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A THEORETICAL REVIEW OF TECHNIQUES FOR THE REMOTE DETECTION OF METHANE IN UNDERGROUND COAL MINES

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MICROMEDIA

JACQUES, WHITFORD AND ASSOCIATES LIMITED

CONSULTING GEOTECHNICAL and MATERIALS ENGINEERS

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March 30, 1983

Canmet
Cape Breton Coal Research Laboratory
210 George Street
Sydney, Nova Scotia
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Attention: Mr. D. Bruce Stewart, P.Eng., Manager

Dear Mr. Stewart:

RE: CONTRACT NO. 0SQ82-00068

We are pleased to submit herewith the original and five copies of our report entitled A Theoretical Review of Techniques for the Remote Detection of Methane in Underground Coal Mines. This report was prepared under authorization of Supply and Services Canada, Contract No. 0SQ82-00068 on behalf of the Cape Breton Coal Mine Research Laboratory, Sydney, Nova Scotia.

Dr. Lutwick and I wish to thank Canmet for the opportunity of having performed this work and sincerely trust that this report meets all your requirements.

Yours very truly,
JACQUES, WHITFORD & ASSOCIATES LIMITED

John A. Amirault, M.Eng., P.Eng.

JAA/kc
cc: G. Dagenais, DSS Hull

Our File: M-1237
Your File: R.N.-2344-2-9051
FC. 213-131-000000-430211-0421
Contract Serial No.: 0SQ82-00068
Scientific Authority: D. Bruce Stewart

A THEORETICAL REVIEW OF TECHNIQUES FOR THE REMOTE DETECTION OF METHANE IN UNDERGROUND COAL MINES

A REPORT

PREPARED BY:

JACQUES, WHITFORD AND ASSOCIATES LIMITED
IN ASSOCIATION WITH
NOVA SCOTIA RESEARCH FOUNDATION

MICROMEDIA

134 pp

Halifax, Nova Scotia

March 30, 1983

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1.0 INTRODUCTION

1.1 Statement of Work:

This theoretical review of potential methods for the remote detection of methane in underground coal mines was commissioned by Supply and Services Canada on behalf of CANMET Cape Breton Coal Research Laboratory in Sydney, Nova Scotia. Contract No. 0SQ82-00068, authorizing the work, was issued to Jacques, Whitford and Associates Limited, Halifax, Nova Scotia dated 3 August 1982 following an invited tender competition submitted in July of 1982.

The terms of reference for the study were established by the Scientific Authority, Mr. D. Bruce Stewart, Manager of the Cape Breton Coal Research Laboratory and are reproduced below.

STATEMENT OF WORK

BACKGROUND

"Explosions have plagued the coal mining industry since its earliest days. While there have been many explosions in which coal dust has been responsible for most of the loss of life and damage, ignition of the dust has almost invariably been caused by prior ignition of firedamp (firedamp is mostly methane with traces of higher hydrocarbons, carbon dioxide and nitrogen). The fire damp which has been stored in the coal and surrounding strata migrates into the mine workings through cracks and other porosities in the various strata, is released by breakage and comminution of the coal face and is emitted directly from the coal face. In operating mines, 30 to 60 cubic metres of methane gas are often "made" per ton of coal produced.

Coal mine workings are ventilated to reduce the methane concentration to well below the lean explosive limit. Hand held methanometers and fixed position

continuous monitoring instruments are used to measure methane concentrations in the work places. In spite of these precautions methane gas accumulations are not uncommon and gas explosions still plague the industry.

It is hoped that the contract will suggest methods which could improve the detection of methane in coal mine workings. It is intended that the effort will be primarily directed toward the detection of relatively infrequent high methane concentrations (methane layers, bleeders, blowers, face flushing from the gob, accumulations in roof cavities etc.)

STATEMENT OF WORK

1. The contractor is to visit an underground coal mine(s) (specific mine(s) to be decided by negotiation with the Scientific Authority to acquaint himself/herself with the physical environment and existing methane measurement monitoring approaches.

2. The contractor will then consider the various techniques and approaches which could be used to detect +1.5% methane concentrations in air but the identification of promising approaches which could, with further development, lead to a rapid convenient way of detecting the presence of +1.5% methane concentrations in coal mine workings.

3. The contract is not intended to definitively pursue any one approach but limited to preliminary bench scale laboratory testing to demonstrate the feasibility of promising approaches and techniques is envisaged.

4. The contractor should bear in mind that the desired end result is not an accurate analytical instrument to measure methane concentrations in air but the identification of promising approaches which could, with further development, lead to a rapid convenient

way of detecting the presence of +1.5% methane concentrations in coal mine workings.

As an example, one result might be the identification of an approach which could be developed into a hand held emittor device which when pointed at elevated methane concentrations would cause them to emit a bright orange glow visible to the naked eye.

5. The Department of Energy, Mines and Resources recognizes that this theoretical review may not produce any promising techniques or approaches which warrant further development."

In accordance with our proposal the work was completed by personnel identified as follows:

John A. Amirault, M.Eng., P.Eng.
Vice President, Mining
Jacques, Whitford and Associates Limited
Halifax, Nova Scotia

Gerald D. Lutwick, Ph.D.
Senior Research Officer
Head, Analytical Section
Nova Scotia Research Foundation
Dartmouth, Nova Scotia

The task was completed during the period September 1982 to March 1983.

1.2 Acknowledgement:

The authors of the report wish to acknowledge with appreciation the assistance of all of those who contributed information and advice used in the preparation of this report. We particularly thank Mr. Stewart and the staff of No. 26 Colliery in coordinating the visit underground.

1.3 Introductory Comments:

Coal seams are formed by the slow alteration of vegetable matter in the presence of moisture and in the absence of air. Heat, generated by the pressure of accumulating sediment overburden, assists in the process. During the coalification process, various gaseous hydrocarbons are also formed. From a coal mining standpoint, the most important of these hydrocarbons is methane - a member of the paraffin series of gases with chemical formula expressed as CH_4.

Most of the methane gas escapes from the coal to the surrounding strata - however large quantities of the gas remain adhered to the coal. In the course of mining, methane may evolve from both of these sources to present hazards to the coal mining operation.

The presence of methane in coal mine workings presents serious safety hazards to the coal mine operator. In excessive concentrations, the gas is suffocating due to the displacement of oxygen. At lower concentrations, methane will either burn or explode when mixed with air. The percentage of methane in the mixture required to produce either burning or explosion depends on a variety of factors such as:

- ignition source
- presence of other combustible or inert gases or dusts
- amount of oxygen
- water vapor
- temperature
- pressure.

It is generally accepted that methane is explosive in the range of 5 to 15 percent when mixed with normal mine air. Once a gas explosion is started, coal dust can be raised to the mine atmosphere and the potential for a more dangerous, coal dust, explosion exists. Gas fires or explosions may initiate fires in other materials such as wooden mine supports and in the coal itself.

The hazards of methane are discussed in more detail under the appropriate section of this report; however, these brief comments will serve to introduce the nature of methane for the purpose of outlining the rationale of the study into the remote detection of methane.

1.4 Rationale of the Study:

In view of the hazards associated with the occurrence of methane in coal mines, the detection and measurement of the quantity of methane in the coal mine atmosphere is of prime concern. All instruments currently available to the mine operator to assess methane concentration require that either a sample of the gas be transported to the measuring device, or that the measuring device be placed within the atmosphere to be sampled.

Because of the mode of occurrence and the properties of methane, it may be either difficult or dangerous to procure a sample, or to expose personnel and equipment to the methane atmosphere. The thrust of this study is to investigate methods of detecting the presence of methane in concentrations exceeding 1.5 percent by volume in a remote sense. Should systems exist which have the potential for adaption to underground coal mine conditions, benefits would accrue to the miner, mine operator and mine inspector in terms of increased ability to detect dangerous concentrations of methane in a safer manner than exists at present. Increased awareness of dangerous concentrations of methane will result in a safer working environment for the coal miner, a safer and therefore more economical coal mine and a safer instrument and operating procedure for methane detection by the mine examiner and mine inspector.

Clearly, investigations into instrumentation for remote methane detection is an appropriate area of research for the Cape Breton Coal Mines Research Laboratory who have commissioned this theoretical review.

1.5 Methodology of Study:

The study was conducted in three stages:

(i) Data Collection:

The collection of data was performed over the period September 1982 through January 1983 and consisted of liaison with the scientific authority, mine site visit, literature search and a canvassing of appropriate research facilities and instrument manufacturers via correspondence and telephone communication.

(ii) Data Evaluation:

Evaluation of information with respect to the suitability of the detection technique and its application to the coal mine environment was performed jointly by the participants as the data was received.

(iii) Report:

The report was jointly prepared to highlight the key information areas and to discuss those systems with the highest potential for adaption to underground coal mine conditions.

1.6 Report Format:

This report is presented in nine major sections dealing with the key issues of the theoretical review. For the purpose of this report, it is assumed that the readers are generally well informed in matters relating to formation and occurrence of methane in coal mines and coal mining operations. Accordingly, the report will only deal with these issues to the extent necessary to link the use of various instrumentation methods to the physical conditions of the coal mine environment.

The first three sections introduce the subject, outline the sources of information and discuss the nature and relationship of methane to coal mines. Sections four and five are concerned with methods of gas analysis in general and methods for the detection of methane currently in use in coal mines.

Sections six and seven discuss methods of remote detection of gases and focus on those methods which have application for use in underground coal mining operations.

The final two sections of the report present recommendations on remote methane detection systems that may find application in underground coal mines, and present details of factual information in appendix format.

2.0 SOURCE OF INFORMATION

Due to the preliminary nature of this review and the broad base of information sources accessed, it is considered prudent to provide as a part of this report as much of the original information as possible. To this end all correspondence and documents that are particularly relevant to remote detection of methane are attached as Appendix 2.0.

2.1 Scientific Liaison and Mine Visit:

During early September, arrangements were made for the study participants to meet with the Scientific Authority; Mr. D. Bruce Stewart, Manager, Cape Breton Coal Research Laboratory in Sydney, Nova Scotia. During this meeting, discussions were held to appraise the investigators with the detail thrust of the study and to focus attention on some of the previous and current work in the field. Copies of previous Canmet reports relating to methane in coal mines were reviewed. Information on groups conducting research in the area of mine gas detection was received.

The manager also coordinated the arrangements for a tour of the Devco #26 Colliery in Glace Bay, Nova Scotia. The mine site tour involved discussions with the site personnel, tour of the control facility on surface, the out station and the sensor installation on 13 N wall face.

The purpose of the mine site visit was twofold:

(1) to gain familiarity with the underground coal mine environment;
(2) to view a modern ventilation monitoring system.

The visit served to allow direct exposure to the physical environment of the mine, and the conditions under which any instrumentation would have to function.

The Cape Breton Development Corporation has recently commissioned a modern ventilation and gas monitoring system to permit ventilation data, procured in the operating areas

of the mine, to be monitored and processed in a control facility on surface. The application and integration of this latest technology in ventilation system monitoring is considered to be among the most modern in North America.

The monitoring system is concerned with three major areas:

(1) wall face ventilation
(2) fan performance
(3) methane drainage.

The wall face ventilation parameters included intake and return air quality and quantity. Fan performance parameters such as surface air temperature, atmospheric pressure, fan pressure, bearing temperature and vibration are measured. The methane drainage system is monitored by measuring the vacuum on the pump, methane concentration and flow rate.

The various sensors, located at or near the working areas, are linked by cables to "out stations" which function as a terminal where the signals are received from the sensors to operate automatic trip functions, to control alarm systems and to receive command signals from surface. The out stations can accept up to eight analog signals and nine on/off signals which are then transmitted to a surface master station via a 7 pair shielded cable.

On surface, the information is monitored by a computerized facility which allows for up to 8 hour storage of the most recent data. The system continuously scans and interrogates each out station for the various measured parameters. A color video display terminal allows the operator to "call up" any one of the out stations for immediate review. Preset alarm levels activate audible and video alarms on surface and underground. Hard copies of status reports at any particular out station may be obtained as required. Computer programs have been develped to manipulate the data; for example to produce histograms of methane content over a shift or week, etc.

The system allows for the procurement, storage and manipulation of voluminous data which may be used by mine management for mine operational control in a manner not previously available. Use of historical records will enable the designers of mine ventilation systems to work with a much higher degree of sophistication and hence quality of results.

The details of the above mentioned system are discussed by Schwartz listed as a reference.

The ventilation monitoring system is most important from the point of view of the application of modern technology within the harsh coal mine environment. It demonstrates the ability to assemble and modify high technology equipment for coal mine use.

The unusually harsh operating conditions particularly for sensitive mechanical and electronic instruments was noted. It was obvious to the investigators that any instrumentation designed for use underground must be able to withstand variations in temperature and humidity, long travel distances to and from the operating faces, vibration associated with conveyances and manual cartage, and dusty conditions. Controls and readout must be compatible with operation under extremes of light intensity, i.e. darkness or spot light. Electrical power sources and the equipment itself must be compatible with regulatory requirements.

2.2 Literature Search:

A search of relevant literature was conducted using the library facilities available at The Nova Scotia Research Foundation. Appropriate key words were developed and utilized to address various scientific data banks. A list of the data banks accessed is appended to the report as Apendix 2-1.

Because of the dynamic nature of computerized data banks it is important to note this search was conducted during November 1982 and was limited to information published

since 1970. While new data is continually being added to the reference list, new information may already be several years in arrears of actual research findings by the time it is published and so referenced. While every effort was made to access all up-to-date data, research work may be completed which has not yet been referenced.

Reference titles and/or abstracts were reviewed to seek published information relating to the remote detection of hydrocarbons and methane in particular.

Hard copies of relevant publications were obtained and reviewed in detail. A list of such publications is presented as Appendix 2-2.

2.3 Research Institutes:

Various research institutes, government and private laboratories and government agencies were canvassed to determine what activity if any was in progress specific to remote methane detection. Initial contact was made by letter followed up by telex and telephone communications if warranted.

One contact with Dr. Susan Till at the Canadian Center for Remote Sensing in Ottawa, proved particularly useful in suggesting potential researchers and was followed up by a personal interview with Dr. Till in Ottawa. Dr. Stephen V. Gentry, SMRE of the Health and Safety Executive in the UK provided a complete listing of all instruments currently in use in Britain. A summary sheet is provided in Appendix 2.0.7.

The USBM are engaged in the use of Raman scattering and have issued a contract to build a prototype system. This activity should be monitored for developments.

Homer research laboratories of the Bethlehem Steel Corporation have developed prototype instruments for application to remote methane detection in coal mines. No

direct contract was established with Homer due to time considerations; however results of their work are due to be presented at the conference of Lasers and Electrooptics in the spring of 1983.

The Graduate Research Centre in Beaverton, Oregon is active in the development of Lasers for methane detection under a grant from Homer Research Laboratory. Notes on telephone communication are attached as Appendix 2.0.10.

Due to program timing and contract budget limitations, efforts to pursue suggestions and contacts were terminated in late January. Certain contacts which may be worthy of further investigation are contained within the recommendations.

Because of the complexity of the nature of the information sought, there was frequently long periods of time between the request and the response; in some cases 3 to 4 months. In future work due allowance must be made for these time lags in data procurement.

A complete listing of the agencies contacted is attached as Appendix 2-3.

2.4 Instrument Manufacturers:

The major manufacturers and/or suppliers of methane detection instruments in Canada and the United States of America were contacted by letter. These contacts were basically of two types; manufacturers of mine instrumentation, and manufacturers of environmental instrumentation.

The manufacturers of mine instrumentation responded generally to the effect that no such instrumentation was available commercially. Furthermore, no comments were made if any research was being conducted into related areas. This response is to be expected as the development of new instrumentation is normally closely guarded for commercial reasons.

The response received from the manufacturers of atmospheric environmental monitoring equipment was more encouraging. These firms are being engaged by government agencies to develop remote sensing systems for the detection of gaseous effluents from industrial plants, oil refineries, gas processing and transmission facilities. A major related application is the inspection of natural gas transmission lines for evidence of gas leaks using portable equipment from the ground surface near the line and also using airborne equipment. Further details of such systems are given under the appropriate section of the report.

Three Canadian firms located in Toronto were identified as having experience in the field of remote methane detection. Moniteq offer two instruments for the remote sensing of hydrocarbons which they feel could be applied to methane. OPTEC inc are building a detection system based on Raman scattering. OPTO-ELECTRONICS are building a system which employs infrared absorption as a detection technique.

An American firm, G.P. Elliott Electronic Systems Ltd. of Houston are currently marketing a laser based gas detection system used to scan plant sites from an on-site tower.

All of the above mentioned firms were most helpful in providing technical literature and telephone commnication relative to their systems. Relevant correspondence and documentation is attached as Appendix 2.0. A complete listing of the instrument manufacturers contacted is attached as Appendix 2-4.

2.6 Laboratory Experimentation:

Prototypes of systems identified which have potential for use in remote detection of methane underground have been developed by various agencies. The fact that the systems function is a matter of record. There is no value in redoing experiments to verify the technique.

Instrumentation which had been developed for specific applications, e.g. helicopter or tower mounted, are not readily available on a loan basis to run any trials. Any testing would require major modifications to existing units which is beyond the scope of this theoretical review.

Laboratory testing was envisaged to prove remote sensing techniques which had not been previously used. No such techniques were determined by the study therefore no laboratory testing was performed.

3.0 METHANE

3.1 Properties of Methane:

Methane is the simplest of the paraffinic hydrocarbons consisting of four hydrogen atoms and one carbon atom per molecule. Methane exists as a gas at temperatures and pressures found in coal mines. Some characteristics of methane are listed in Table I.

The wide range of explosibility when mixed in air is the key hazard associated with the gas. The fact that it is both colourless and odorless prevents easy detection by human senses. Being lighter than air the gas has a tendency to accumulate in high places which at times may not be easily or safely accessed for detection. Even within the flow of ventilation currents, the gas has a tendency to layer against the roof resulting in stratification of the mine atmosphere.

3.2 Occurrence of Methane in Coal Mines:

It is not the intent of this study to report in detail on the source and occurrence of methane in coal mines. A few comments, however, are in order to briefly outline the basic scientific knowledge available on methane occurrence as it relates to the study of methods to remotely detect the gas.

Coalification of organic materials occurs as decomposing vegetation is accumulated under water in a reducing environment. Methane gas is generated as a part of this process. During these early stages, most of the methane generated escapes to the atmosphere; however, as the "neo" coal is buried by sediment overburden, some methane is trapped within the coal seam. With time, some of the gas continues to escape to the surrounding strata where it may be stored. Signficiant amounts of gas is also retained by the coal itself. Some researchers suggest that the process of methane production is on going, but at a rate inversely proportional to the age of the coal.

TABLE 1

Characteristics of Methane

Boiling Point	-161.5°C
Melting Point	-182.5°C
Density of Dry Gas and N.T.P.	0.717 g/CC
Critical Temperature	-82.2°C
Critical Pressure	45.8 Atmosphere
Calorific Value	12,000 Kcal/Kg
Explosibility Range	5 - 15% in air
Colourless	
Odourless	

Estimates of the total amount of methane produced are as large as 46,000 cubic feet per short ton; 98 percent of which escapes from the coal with time. As the methane gas escapes to the surrounding strata, structural conditions may exist to trap the gas within porous sediments and allow it to accumulate at elevated pressures. During mining activities, fracturing of roof and floor strata due to mining will permit pressurized gas to flow and hence enter the mine. In mining terminology, flows of methane gas into the mine openings are known as "bleeders", "feeders", "blowers", "gas fissures", etc. Flows of methane into the mine workings can originate from either the floor strata, the coal itself or the roof strata and can occur with any level of intensity.

Within the coal itself, methane is known to occur in two modes. The first mode or free methane is contained within the fractures, the cleat and the pores of the coal. This gas is emitted relatively freely as the coal is mined. A second mode of occurrence is adsorption upon the coal particles themselves. The emission of methane from either mode in the coal is a much slower process than from feeders, starts as soon as the coal is cut and may continue for weeks after the coal has been mined.

Gas flows of low volume, and pressure cause relatively minor problems to the mine operator and are dispersed by normal ventilating currents. Gas flowage of high pressure and volume may be catostrophic and at times be accompanied by a blow out of significant quantities of coal. Such occurrences are commonly known as "gas outbursts".

Gas emissions show a tendency to increase with depth of mining and to decrease with increasing rank of coal. Modern mining methods which employ rapid, high volume mining methods serve to increase the rate of methane emissions into the mine atmosphere. As coal mining proceeds to deeper depths, the problems become compounded in terms of higher volumes of gas, higher gas pressures and higher flow rates.

Methane may also occur from other sources in coal mines such as improperly cased oil and gas boreholes, and distilled from coal during mine fires and blasting operations. These occurrences are relatively rare and will not be discussed further.

3.3 Methane Hazards in Underground Coal Mines:

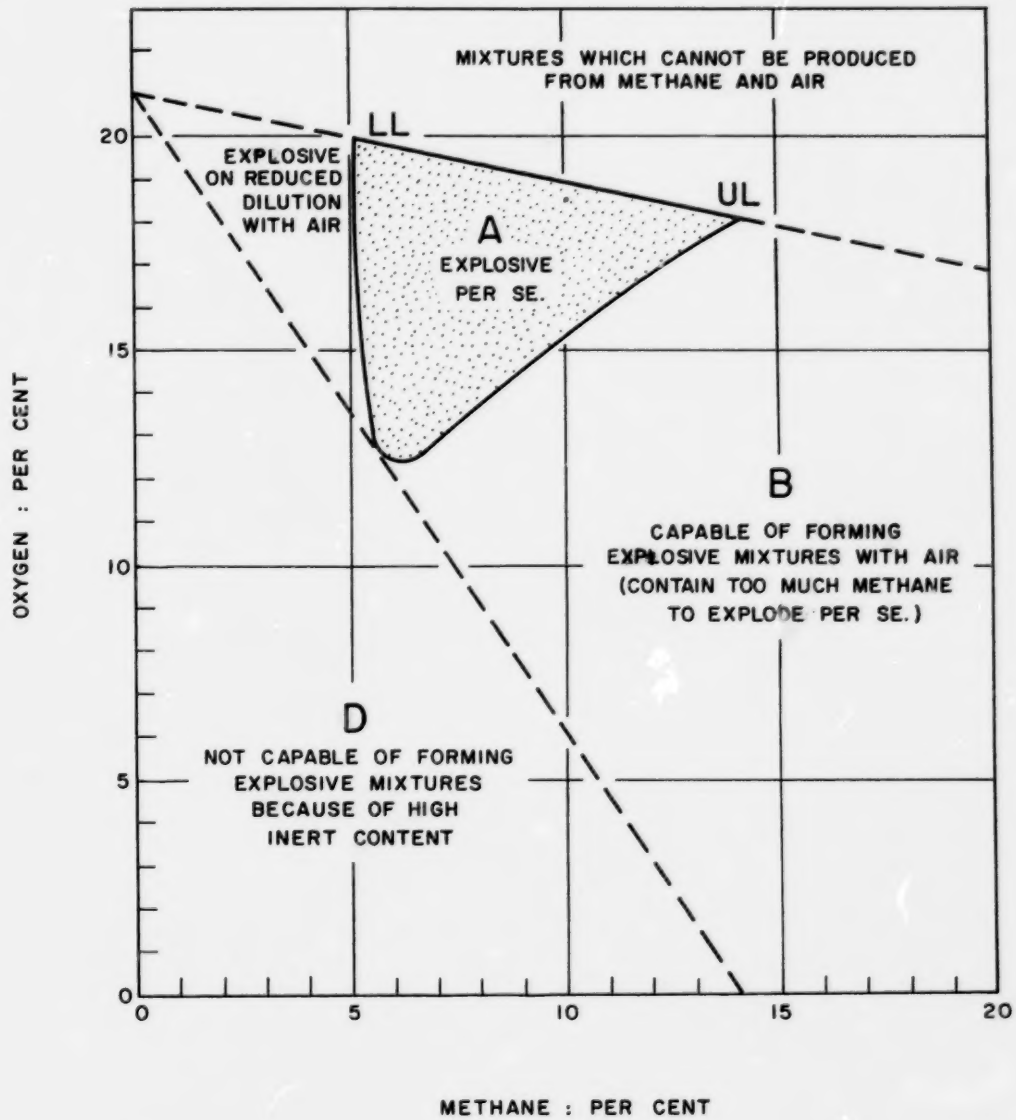
The presence of methane in the mine atmosphere may become a serious hazard to the miner from a safety point of view and to the mine operator by curtailing coal production operations when statuatory limitations are exceeded.

Low concentration (0-1.5%) of methane in the normal mine atmosphere is believed to be relatively harmless. As the methane content in the air increases, a level of concentration is reached which will support combustion for a short period of time. Due to the cooling effect of a large body of air, the flame is soon extinguished.

As the level of concentration is increased, a point known as the "lower explosive limit" is attained at which sustained very rapid burning or explosion may occur. The upper explosive limit is attained when the methane/oxygen ratio is too high to support the rapid combustion. Further increases in methane content causes the mixture to become flamable and finally to be too rich to sustain combustion of any form.

The above phenomena has been long recognized by researchers and coal mine operators. A chart relating methane content, oxygen content and the explosive characteristics of various mixtures of each is frequently used to predict dangerous conditions. An example of such a chart is presented as Figure No. 1.0.

Flowage of high concentrations of methane into the mine



Relation between the quantitative composition and the explosibility of mixtures of methane, oxygen and nitrogen. (The inflammability triangle — after Coward)

INFLAMMABILITY TRIANGLE

FIGURE 1

atmosphere has the effect of depressing oxygen and hence presents a suffocation hazard to underground personnel. Oxygen levels below 16% will not support normal human activity. This hazard is particularly critical in the case of poorly ventilated workings to the rise, which may allow for the complete displacement of the normal mine air and hence life supporting oxygen. Remote detection of methane under such conditions would prove extremely beneficial.

Flamable and explosive mixtures present an explosion hazard which may be initiated from a variety of sources such as:

- blasting operations,
- mechanical sparks,
- electrical sparks, or
- fire conditions, etc.

The explosion hazard is further increased by elevated air pressure and by the presence of other combustible gases such as carbon monoxide.

3.4 Statuatory Limits and Inspection Requirements:

Because of the recognized hazards associated with methane, statuatory limits have been established by regulatory authorities in all coal producing areas of the world. These limits have been established to control activity within the mine in the presence of methane. While there is some controversy over precise action levels, the intent of the legislation is the same. Action levels used within Nova Scotia are quoted from the Coal Mines Regulation Act, Revised Statues of Nova Scotia 1967 as an example.

"Sec 84(2) Rule 2

Electricity shall not be used in any section of a

mine where the methane content of the air about the electrical aparatus or equipment exceeds 1.25 percent as determined by a locked flame safety lamp or an approved detector, ...

If at any time it is found by the person for the time being, in charge of a mine or any part thereof, that by reason of inflammable or noxious gases prevailing in the mine, or any part thereof, or from any cause whatever, the mine or the part is dangerous, every workman shall be withdrawn from the mine or such part thereof as is so found dangerous, ...

Sec 71(3)

For the purpose of this Section, a place shall be deemed to be dangerous if the percentage of inflammable gas in the general body of air in that place is found to be two and one-half percent or upwards. . . . "

To further guard against explosion of methane. All electrical systems must conform to rigid specifications known as "approved" or "permissible" and be certified by the regulatory agency.

Rigid inspection routines are established concerning the monitoring of the methane content relating to competance of personnel, types of equipment frequency of measurement and recording of results. Modern mining systems may also utilize semi-continuous monitors to measure the methane content of the mine air and activate alarms and/or automatically shut off electrical power. One system was briefly described previously.

4.0 GAS ANALYSIS

4.1 Classical Chemical Methods:

The components of a mixture of gases may be analyzed by a variety of methods. Classical chemical methods include colorimetry, gravimetric absorption, and volumetric absorption. More modern analytical methods utilize gas chromatography and electromagnetic phenomena.

An example of colorimetry in current use is the detection of carbon monoxide in the atmosphere by the use of detector tubes. A device, such as a hand pump, is used to draw the sample through the tubes. The tubes are filled with silica gel impregnated with a molybdenum compound which turns green then black as carbon monoxide is absorbed. The color of the tube is compared with a standard chart which indicates the amount of carbon monoxide present. Similarly hydrogen sulfide can be detected by means of lead acetate paper. The paper turns black in the presence of hydrogen sulfide.

Gas samples may be analyzed by volumetric absorption using the Orsat apparatus. In principle, a volume of gas at atmospheric pressure is passed through various reagents which selectively absorb one constituent and the volume of remaining gas is measured after each reagent. The Orsat method in most instances has been displaced by gas chromatographic and infrared methods. These modern methods have the advantage of requiring less handling and manipulation of sample as well as better resolution and higher precision particularly at low concentrations.

Chemical methods of analysis are not adaptable to use in the remote detection of methane. Chemical methods of analysis require the sample to be contacted with the reagent followed by measurement of a property of the resulting product. Contact of sample and reagent requires transporting the sample from the area of interest to a work station. Furthermore, simple chemical methods of analysis do not lend themselves to the determination of methane as methane does not readily enter into chemical reactions.

The foregoing methods of classical chemical gas analysis may not, therefore be considered as having potential for remote detection of methane.

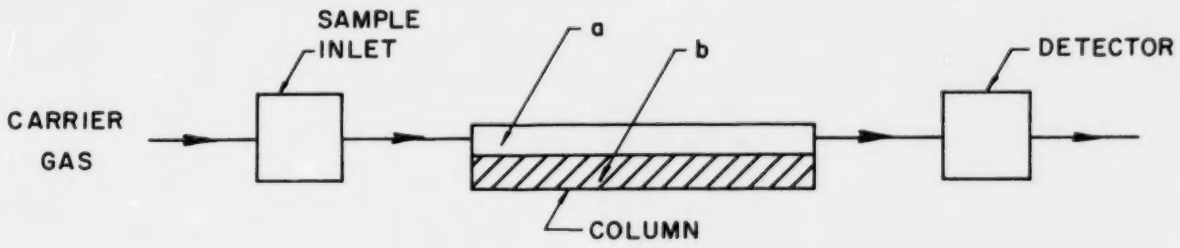
4.2 Gas Chromatography:

Modern gas analysis often utilize gas chromatography which is a method of separating a sample of gas or volatile liquid into its various components. The principle of operation is shown in Figure 2. The hatched area, b, represents a finely divided inert material covered by a thin layer of nonvolatile liquid phase. Area "a" represents the free space between the liquid coated particles through which the carrier gas flows.

When a sample of gas or volatile liquid is injected into the carrier gas stream, the components move through the column at rates dependant of their respective vapour pressures and interactions with the non-volatile liquid phase. Partition of the sample components occurs and each component of the sample emerges from the end of the column as a binary mixture with the carrier gas.

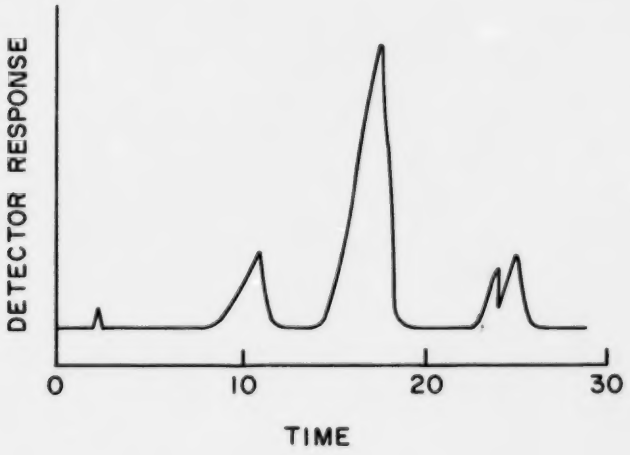
A detector at the end of the column produces a signal relative to the instantaneous concentration of the component in the carrier gas. This signal is plotted in relation to time by means of an electronic recorder and is called a chromatogram. A typical gas chromatogram is shown in Figure 3. The following information can be obtained from the chromatogram: the minimum number of components present, identification of components from retention time the quantity of components from the peak heights or peak areas.

Gas chromatography as an analytical tool requires a sample to be introduced into the carrier gas. In all instances, the sample must be conveyed to the instrument. Gases, such as mine atmospheres, can be collected at the sampling points in evacuated gas sampling containers, pressurized by pump in steel bombs or collected in sealable gas syringes. These devices require personnel to go into areas which are



SIMPLE GAS CHROMATOGRAPH

FIGURE 2



GAS CHROMATOGRAM OF GAS MIXTURE

FIGURE 3

to be sampled.

Gases can also be sampled by means of tubing extending from the gas chromatograph to the sampling point. The sample is then conveyed by pump, through the tubing to the chromatograph.

Gas chromatography is convenient and precise for determining methane in gas mixtures. Specificity for methane is provided by the use of molecular sieve columns. The amount of sample required for the chromotograph is only 10 ml. The need for such a small quantity indicates the possibility of taking mine-air samples in syringes thus saving space, weight and time of sampling. The necessity of injecting the sample into the instrument does not lend itself to remote sensing. The time required for analysis is excessive for use as a warning of impending danger (approximately 10 minutes).

An example of the application of gas chromotography to methane detection in coal mines is reported from Japan. Nabeya, H., C. Inaba, Y. Koyama and M. Sogiska (1981) have reported on the use of a gas chromatographic system tested in the Akabira coal mine, Hokkaido, Japan. The instrument described consisted of two columns and two detectors. The columns were 0.6 meters molecular sieve and 1.0 meters of activated charcoal. The detector consisted of microcells of two-element thermistors in a wheatstone bridge circuit. Using helium as the carrier gas, they were able to separate and analyze the mine atmosphere consisting of hydrogen, oxygen, nitrogen, methane, carbon monoxide and carbon dioxide. The safety of the chromatography equipment was secured by applying explosion proof construction to the underground power unit. All other parts are intrinsically safe.

The signals generated by the chromatograph are transmitted to a surface microcomputer for processing. The microcomputer is interfaced with various devices for storage of data and also activating alarms.

While the foregoing systems may be of interest from the point of view of the application of a modern analytical technique underground in coal mines it does not meet the requirement of this study. It does however document the ability to adapt a complex, sensitive system of instrumentation for use underground. Matters relating to power supply, portability and use of instrumentation subjected to harsh underground mining conditions have been addressed.

4.3 Other Methods:

Other common methods of gas detection involve electromagnetic spectrum analysis and will be discussed in relation to methane detection.

5.0 METHANE DETECTION

5.1 General Comments:

Accumulations of gas occur naturally in the coal and adjacent strata and are liberated as a part of the normal mining process. This gas is termed fire damp and is principally methane. Carbon dioxide and nitrogen are also present in small amounts. The presence of methane within the coal mine environment is a constant hazard to miners.

Knowledge of the presence and concentration of methane accumulation is of vital importance to the safe operation of the coal mine. The detection and measuring of methane has been a concern in coal mines since man began to dig coal out of the ground. Early coal miners burned off the methane. A miner entered the mine carrying a torch and ignited the gas which had collected on the roof. Caged birds were used as detectors of gassy conditions in mines, the birds died when the concentration of methane became dangerous.

The miner's flame safety-lamp was introduced over a hundred years ago to detect methane. The flame safety-lamp develops a distinctive cap over the flame in the presence of methane. Trained personnel are able to identify a gas cap in a 1 to 1.25% methane atmosphere, which is the beginning of the methane danger region. This was the first type of instrument to be widely used to detect methane in coal mines.

Safety legislation demands accurate determination of methane in coal mines and hence the need to supplement the flame safety-lamp to obtain greater accuracy. Modern technology has provided methods of determining methane which have been adapted to coal mines. Current practice of methane detection employs the interaction of methane with electromagnetic radiation, heat transfer characteristics, the calorific value of methane and the ability to separate methane from other atmospheric gases.

5.2 Portable Systems:

Portable methanometers used in mines today consist of two parts, a sensor and a detection readout system. Methane is detected by catalytic oxidation which heats an element in one arm of a Wheatstone bridge causing an unbalance of the bridge. The quantity of methane present is proportional to the unbalance in the bridge and is indicated by a suitable readout device.

A portable absorption gas analyzer has been developed by McClatchie, Edward A., and irwin G. Burrough (1980). The analyzer was capable of measuring the concentration of CO, CO_2, and NO_2. The ability to determine CH_4 was not mentioned. The unit is battery powered and and weighs 15 lbs.

Vronski (1968) developed a method based on the comparison of the brilliance of two platinum filaments, one of which is heated by catalytic combustion of methane. The filaments have the same brilliance when viewed through glass filters corresponding to 0, 1 and 2% CH_4. A difference corresponding to 0.5% CH_4 may be detected.

These instruments may only be used in a remote sense when extension probes are used to transfer the sample from place sampled to the detection instrument. As a consequence of these limitations, the foregoing instrumentation is not considered suitable for the remote detection of methane. They also are not applicable to areas of the mine which cannot be reached safely by the miner.

5.3 Integrated Systems:

Catalytic Combustion:

Most methanometers in service today operate by catalytic combustion of methane. An example of this type of instrumentation is the BM1 Methane Monitor produced by J and S Seiger Ltd.

In the sensor head of these instruments is a matched pair of methane gas detector elements. One element acts as a catalyst in the combustion of methane. During combustion, this element heats up causing an unbalance in the Wheatstone bridge. The current resulting from unbalance in the Wheatstone bridge is proportional to the methane concentration. When the methane concentration is excessive, the output can be used to activate alarms.

These systems require the sensor to be positioned within the area which is being analyzed. The methane being detected diffuses into the detector where it contacts the catalyst and burns. As the concentration of methane changes, there is a time lag resulting from equilibrium of the temperature of the elements with changing gas concentration. The response time of catalytic sensors is of the order of 10 to 15 seconds.

Signals generated by the instrument may be transferred by means of telemetry to a computer in a central monitoring station on the surface. The computer handles data from a number of sensors located in different sections of the mine and can be used to sound alarms and shut down electrical equipment. Supervising personnel can use the information in the computer to implement corrective action for the prevention of dangerous working conditions.

An example of this type of system, Seiger BM1, is used at DEVCO #26 colliery. While remote, in the aspect that the sensors are located underground in the operating areas of the mine and the monitoring and control functions are on the surface it is not remote within the context of this study.

6.0 REMOTE DETECTION OF GASES

6.1 Introductory Comments:

Two types of remote detection of gases may be considered. The first type refers to a system whereby the sensor is remote from the readout. Many of the previous examples of gas analysis may be adapted to operate in this mode for example through the use of sampling pumps, aspirator bulbs, tube bundles etc. A prime example is the BM1 as described in the previous section.

A second method of remote sensing can be envisaged as a situation in which the sensor and readout are in the same position and the presence of methane is detected at some distance i.e. remote from the instrumentation. It is this second approach to which this theoretical review is addressed.

Instrumentation for this form of remote detection of gases normally employs the interaction of electromagnetic radiation with the gas sample to obtain quantitive information of the sample constituents. Instruments vary as to how the electromagnetic radiation is detected, how it is produced and what wavelength is utilized. The variation will depend upon the nature of the molecule to be detected. The major developments of these instruments have been in the application to air pollution studies.

An understanding of these types of detection techniques requires a basic knowledge of the electromagnetic spectrum, the molecular nature of gases, and the phenomena that results from the interaction between the two. These items will be discussed with particular reference to methane.

6.2 Electromagnetic Spectrum:

The electromagnetic spectrum is an array of radiant energy extending from wavelengths of 10^{-12} cm to wavelengths of 10^{6} cm. The electromagnetic spectrum has been divided into various regions according to wave length

and classified by name depending upon the type of instrument used to produce or detect the waves. These regions are illustrated in Table 2. The key characteristics of electromagnetic radiation are wave length or frequency and energy level. These items are related by formula as follows:

$$E = h \frac{c}{\lambda}$$

Where: E = Energy
C = velocity of light
λ = wave length of the radiation
h = plancks constant

Discussion of quantum theory is beyond the scope of this study however suffice to say that specific wave lengths or energy levels of radiation produce specific effects on gas molecules. These effects may be used to identify and to quantify the molecule present. The choice of effective wave lengths, depends upon the molecule being investigated.

The radiation which is absorbed and re-emitted shows an increase in wavelength implying a decrease in energy. The energy lost by the incident radiation goes to increase the internal vibrational and rotational energy of the molecules. This energy within the molecule is restricted by quantum rules to certain discrete values. Hence the energy abstracted by the medium from the incident radiant energy is limited to certain specific values characteristic of the molecular species involved.

The response of methane to absorption of electromagnetic radiation is limited to wavelengths longer than the visible region of the electromagnetic spectrum. This limitation is imposed by the structure of the methane molecule and the absence of a dipole. Thus the use of infrared radiation to induce absorption and reflectance shall be considered as possible means to remotely detect methane.

TABLE 2

REGIONS OF THE ELECTROMAGNETIC SPECTRUM

Wavelength Range, cm	Region
10^{-12} - 10^{-11}	cosmic rays
10^{-11} - 10^{-9}	gamma rays
10^{-9} - 10^{-7}	x-rays
10^{-7} - 2×10^{-5}	far ultraviolet
2×10^{-5} - 4×10^{-5}	near ultraviolet
4×10^{-5} - 7×10^{-5}	visible
7×10^{-5} - 3.5×10^{-4}	near infrared
3.5×10^{-4} - 3×10^{-3}	middle infrared
3×10^{-3} - 3×10^{-2}	far infrared
3×10^{-2} - 10^{6}	radio waves, microwaves

6.3 Infrared Absorption:

Methane absorbs infrared energy which can be detected by measuring the quantity of radiation absorbed. Two single ended commercial instruments, Gaspils and Plumetracker (Moniteq), are designed for remotely detecting methane, sulfur dioxide and oxides of nitrogen. Both instruments utilize natural sources of electromagnetic radiation.

Gapsils is designed to detect leaks in gas pipelines. The instrument detects these leaks by sensing the absorption of infrared radiation against the earth's surface background radiation. Radiation from the earth's surface is collected by a telescopic lens and relayed through filters to a cryogenically cooled infrared detector. A Z-80 based microprocessor performs a variety of data processing functions including signal averaging, balancing, normalization and formatting.

Plumetracker is used as a mobile unit, ground or air, for the remote detection of SO_2 and NO_2 in gas plumes. The gases are detected by their absorption of scattered solar ultraviolet radiation. Interferent absorption from other gases are avoided by careful selection of wavelength measured. The main components of Plumetracker are a light gathering telescope, a grating spectrometer with multiple exit slits and signal processing electronics.

Other instruments utilize lasers as an incident source of infrared radiation. The EAGLE system by G.P. Elliott uses this principle to scan industrial plant sites for hydrocarbon leaks.

Technical descriptions of the above systems are attacted as Appendix 2.0.

There are many types of lasers available, from solid state lasers to large gas lasers. Simple gas lasers can be run for long periods of time and some, such as the carbon dioxide laser, can be tuned to more than one emission line.

Lasers, an acronym for light amplification by stimulated emission of radiation, have been applied as sources of radiation for air pollution measurements. Laser light has several characteristics which make lasers highly desireable sources of electromagnetic radiation. The emitted radiation from lasers is highly monochromatic and is transmitted with low divergence.

The basic feature of remote monitoring with lasers is long-path absorption. A laser, tuned to a wavelength which is strongly absorbed by the gas of interest, transmits a beam through the area of interest onto a detector. If the gas is present, the detector signal will be attentuated by an amount proportional to the quantity of gas. A second laser wavelength, not absorbed by the gas, provides a reference signal.

When two wavelengths are used, as previously described, the system is known as DIAL (Differential Absorption LIDAR). Dial systems have been studied for sensing of atmospheric gases by Murray (1977). These systems have used ultraviolet, visible and infrared radiation. Single-ended systems are described in which topographical features are used as reflectors which return the emitted radiation to the detector.

Lidar (light detection and ranging) is a technique in which a very short pulse of light is transmitted into the atmoshpere. A fraction of this light is elastically back scattered and collected by a sensitive detector. Aerosol particles cause an increase in signal whereas absorbing molecules cause a decrease. The distance between the detector and pollutant is obtained from the time required for and pulse to go out and back to the detector.

6.4 Raman Spectroscopy:

When radiant energy falls upon a medium which is partially transparent, the constituents of the medium absorb and reradiate with a change of wavelength. The

radiation which is re-emitted shows an increase in wavelength implying a decrease in energy. The corresponding difference in wavelength between the incident and the re-emitted radiation is known as the Raman shift. Raman spectroscopy is concerned with this phenomenon. Similarily emitted raditation is also observed on the short-wavelength side of the exciting line corresponding to an increase in energy. This phenomena is much weaker than Raman.

Raman shifts are characteristic of specific interatomic valence bonds within the molecule. Since there are several different bonds in most organic molecules, each bond may absorb various quantized amounts of energy and every substance will show several distinct Raman lines. The resulting spectra are characteristic of the absorbing molecule and qualitative identification is readily achieved by comparison of the spectrum with spectra of known compounds. Quantitative analysis is possible because the intensity of the Raman radiation is proportional to the concentration of the scattering material.

Raman spectroscopy has been applied by Strauch (1972) using the Lidar technique to the determination of water in the atmosphere. Schildkrant (1972) using the Lidar technique to the determination of water in the atmosphere. Schildkrant (1972) reports on the use of remote Raman spectroscopy to determine nitrogen, oxygen and carbon dioxide. The use of Raman spectroscopy, for the remote sensing of troposphere pollutants, has been reported by Browell (1977) using the Dial technique. The majority of the systems which have reached commercial production are designed for measurement of low concentrations of pollutants. The order of sensitivity required for analysis of air pollution may not be required to determine methane in coal mines.

Techniques using Raman scattering are being pursued by the USBM for the purpose of developing a remote methanometer

for use in coal mines. This work should be monitored.

6.5 Other Techniques:

Two other methods were originally conceived as having potential for use as a means to remotely detect methane.

The principle of thermography which is currently used to detect loose rock underground by temperature differential may be worthy of further research. The investigation dod not determine any work in this field.

The detection of methane by acoustical methods based on the principal of differential density between methane and the air mass was referenced by Gentry, SMRE. Problems with interference by water vapor was cited as a major problem with the system and consequently work in the UK has been discontinued.

7.0 TECHNIQUES WITH POTENTIAL FOR REMOTE DETECTION OF METHANE IN COAL MINES

Review of information available suggest two types of instrumentation which are applicable to remote detection of methane in coal mines. These are infrared (notably differential absorption type) and Raman spectroscopy. As analytical tools, these methods have reached a high degree of refinement as shown by their use for remote monitoring of the troposphere.

Infrared and Raman spectroscopy are similar with regard to the sources of radiation, nature of detectors, methods of amplification and recording instrumentation. Both techniques involve the interaction of electromagnetic radiation with the molecules of gas, in this case methane.

Infrared spectroscopy is concerned with comparing the intensity of the transmitted radiation with the intensity of incident radiation. The absorption of infrared radiation occurs at definite wavelengths which are characteristic of the molecule. Raman scattering can occur at any wave length and the wavelength of the scattered radiation is a different wavelength than the incident radiation. Lasers are used as sources in applying these techniques to remote sensing because they yield intense monochromatic radiation which facilitates detection.

A practical methanometer for use in coal mines as a remote sensor of methane should be capable of scanning at distances of 5 to 15 metres. This would allow the determination of methane in inaccessible areas by remote means.

Conditions in coal mines, such as the presence of coal dust and water vapor which attentuates the radiation, necessitates the use of a high intensity source, such as a laser, and highly sensitive detectors with very low noise characteristics. The very low noise characteristic is required for measuring low concentrations of methane which would generate a low response signal.

Infrared and Raman spectroscopy techniques have the necessary inherent characteristics to determine methane in coal mines.

The major characteristic is their immediate response to changes in methane concentrations, thus providing the quickest means of sounding alarms. The instrumentation is also capable of being specific for the detection of methane. Each system may be ranged for detection at variable distance from the detector.

Future developments in the use of infrared and Raman spectroscopy to the remote detection of methane in coal mines will be in the development and use of more sensitive detectors and more intense sources of radiation adapted to the coal mine environment. These developments will be paralleled by the miniaturization of instrumentation which will be significant in its application as a portable tool.

Both detection systems developed by Moniteq, Gaspils and Plumetracker; employ passive, ambient radiation sources. They suggest that similar natural infrared from the rock may hold potential for use as a radiation source. Furthermore they suggest reflectance of a modulated infrared source from the mine walls may be worthy of investigation.

Within the confines of this theoretical review, infrared and Raman spectroscopy are the only techniques which appear to have the required properties for remote detection of methane in coal mines.

8.0 RECOMMENDATIONS

The results of this study show that analytical techniques using electromagnetic radiation show promise for use in the remote detection of methane. These techniques have been applied to measurements of atmospheric pollutants at distances in the kilometre range using infrared absorption and Raman effects. Instruments should be adaptable to measuring methane in coal mines where the distance of interest is much shorter and the level of concentration of the gas to be detected is much higher.

The U.S. Bureau of Mines (Private communication, D. Litton) has evaluated the feasibility of the Raman technique for measuring methane at a coal face. They have also shown that the components necessary to construct such a methanometer are commercially available. It is estimated that a prototype of this instrumentation will be constructed and tested by December, 1984. It is recommended that progress in this program be monitored.

Infrared technology is recommended for evaluation as a means of determining methane in coal mines. Homer Research Laboratories of Bethleham Steel Corporation have developed a methanometer using absorption techniques. It is recommended that reports of that work be monitored for developments and that direct contract with the laboratory be established.

Work both by the USBM and Horner is now focused on the development of suitable radiation generating devices and detectors that may be used in the application of either technique. Infrared determination of methane requires a source of radiation of 3.3 um wavelength and a means of detecting that wavelength. The most convenient sources that should be investigated are tunable diode lasers (Patel, C.K.N., 1978) which have been used in air pollution studies.

Solid state detectors for infrared radiation have also shown improvements (Levinstein and Mudar, 1975). These detectors span the electromagnetic wavelength regions from the visible to microwave region.

Recent developments in sources and detectors of infrared radiation, coupled with the advances in microprocessors, suggests further study is required into instrumentation based on infrared spectroscopy. It is recommended that this study would examine infrared spectroscopy in depth to determine the feasibility of construction of a methanometer, stationary and portable, for use in coal mines.

The activity of Canadian firms in the field of remote detection of gases is worthy of note. It is recommended that further contact be established with these firms to explore the adaptation of available systems to the coal mine environment. This "high technology" area of scientific development is at an early stage and may provide an opportunity for new developments in instrumentation.

To enable application of the various techniques to coal mines developments will be required in the area of equipment modification. Equipment designed for use on surface will have to be miniaturized and power systems modified to permit portable operation within a gassey environment. Further work relative to these areas is recommended.

Further research into the use of ambient incident radiation, for example, the heat of the rock and the use of the coal/rock surface and aerosol dust particles as reflectors is recommended.

APPENDIX 2.3

List of Research Agencies Contacted

	Response
Mr. Kurt Anlauf Atmospheric Environment Services 4905 Dufferin Street Downsview, Ontario M3H 5T4	Nil
Canada Center for Remote Sensing 2464 Sheffield Road Ottawa, Ontario M3H 5T4 ATTENTION: Mr. E.A. Godby, Director General	Yes
Dr.-ing. Friedrich Benthaus Dienstlich 4300 Essen 13 (Kray) Franz-Fischer-Weg 61 ATTENTION: Dr.-ing Friedrich Benthaus, Bergassessor A.D.	Nil
Central Mining Institute Safety in Mines Institute Experimental Mine "Barbara" ul Pdleski 72 43 - 190 MIKOLOW POLAND ATTENTION: Dr. Pawel A. Krzystolik Deputy Director, Assistant Professor	Nil
Mr. Ken Barron, Manager Coal Mining Research Center University of Alberta Edmonton, Alberta T6G 2E2	Yes

Energy, Mines and Resources Canada — Yes
555 Booth Street
Ottawa, Ontario

ATTENTION: Mr. J.A. Bossert, P.Eng.
Manager/Certification Officer
Canadian Explosive Atmospheres Laboratory

Dr. Robin Chakravorty — Nil
3303 - 3rd Street, N.W.
Calgary, Alberta
T2L 2A7

National Coal Board — Nil
Directorate of Mining Environment
17 South Parade
Doncaster, Yorkshire
Doncaster 66611

ATTENTION: Mr. R.A. Swift, Chief Ventilation Officer

Steel City House — Yes
West Street
Sheffield, SI 2GQ

ATTENTION: Dr. A.G. Johnston,
Director of Research and Laboratory
Services and Head of SMRE

U.S Bureau of Mines — Yes
Cochrans Mill Road
Post Office Box 18070
Pittsburgh, PA 15236

ATTENTION: Mr. John N. Murphy, Research Director
Also: Mr. Dave Litton

Oregon Graduate Center
19600 N.W. Walker Road
Beaverton, Oregon
U.S.A. 97006

ATTENTION: Dr. R.A. Elliott — Yes
(by telephone)

APPENDIX 2.4

List of Instrument Manufacturers Contacted

	Response
Bacharach Instrument Company 625 Alpha Drive Pittsburgh, PA USA 15238	Nil
Dr. C. Cumming Barringer Research Limited 394 Carlington Drive Rexdale, Ontario M9W 5G2	Nil
Mr. W.A. Crosley Executive Vice President Detector Electronics Corporation 6901-W 110th Street Mineapolis, Minnessota USA 55438	Yes
G.P. Elliott Electronic Systems 3/D International Tower 1900 West Loop South Suite 1460 Houston, Texas USA 77027	Yes
Mr. Ken Brown, President MSA Canada 148 Norfinch Drive Downsview, Ontario M3N 1X8	Yes
Mr. Victor Ward Moniteq Limited 630 Rivermede Road Concord, Ontario L4K 1B6	Yes
National Mine Service Company 4900/600 Grant Street Pittsburgh, PA USA 15219 ATTENTION: Mr. Mike Formica, Sales Engineering Manager	Nil

Mr. S. Sizgoric
Optech Limited
701 Petrolia Drive
Downsview, Ontario
M3J 2N6

Yes

Dr. John Ried
Opto-Electronics Limited
Unti 9, 2538 Speers Road
Oakville, Ontario
L6L 5K9

Yes

LIST OF APPENDICES

2.0 Relevant Correspondence
2.1 List of Data Banks Accessed
2.2 List of Relevant Publications
2.3 List of Research Agencies Contacted
2.4 List of Instrument Manufacturers Contacted

Appendix 2.0

LIST OF RELEVANT CORRESPONDENCE

(1) EMR Authorization
(2) Sample Contact Letter
(3) OPTECH (Jan. 27, 1983)
(4) OPTO Electronics (Jan. 13, 1983)
(5) Moniteq (Dec. 14, 1983)
(6) G.P. Elliott Systems Limited
(7) Health & Safety Executive
(8) Canada Centre for Remote Sensing
(9) Pitsburgh Research Centre
(10) Notes on telephone conversation - R.A. Elliott
Oregon Graduate Centre

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Science and Technology
Science et Technologie

APPENDIX 2.0.1
Cape Breton Coal
Research Laboratory
210 George Street
Sydney, Nova Scotia
B1P 1J3

Your file Votre référence

Our file Notre référence

September 13, 1982

To whom it may concern:

Mr. J.A. Amirault, P.Eng. of Jacques, Whitford and Associates Ltd. has been awarded a contract by Energy, Mines and Resources to review possible techniques to improve the detection of methane in underground coal mine workings. It is hoped that this contract will identify promising approaches which, with further development, could lead to a rapid, convenient way of remotely detecting methane concentrations.

Any assistance that you or your group can provide to assist Mr. Amirault would be appreciated.

Yours very truly,

D. Bruce Stewart, P.Eng.
Manager, Cape Breton Coal
Research Laboratory
Telephone: 902-539-5344

DBS/dmg

Canada Centre for Mineral and Energy Technology,
555 Booth Street,
Ottawa, Canada.
K1A 0G1

Centre canadien de la technologie des minéraux et de l'énergie,
555, rue Booth,
Ottawa, Canada,
K1A 0G1

Canada

JACQUES, WHITFORD AND ASSOCIATES LIMITED

CONSULTING GEOTECHNICAL and MATERIALS ENGINEERS

SITE INVESTIGATIONS
BLASTING CONTROL
FOUNDATIONS and EARTHWORKS
MATERIALS
HYDROGEOLOGY

1046 BARRINGTON STREET
HALIFAX, N.S. B3H 2R1
(902) 423-6325
TELEX 019-21745

October 7, 1982
Project No. M1237

Bacharach Instrument Company
625 Alpha Drive
Pittsburgh, PA
USA 15238

ATTENTION: Walter Haupt, Sales Manager

Dear Sir:

RE: METHANE DETECTION IN COAL MINES

We have been commissioned by Energy Mines and Resources, Canada to review possible techniques which would enable the remote detection of methane in underground coal mines. I attach a letter of authorization and a copy of the contract statement of work outlining the general parameters of the study.

To date, a literature search indicates some promising techniques may have been developed or are developing associated with remote atmospheric monitoring using the principle of ramon scattering. Other techniques using, for example, interferometry or differential absorption light detection techniques may also prove of interest.

It may be possible that other properties of methane such as density may be useful in remote detection at elevated concentrations above 1.5%.

Could you advise of any current research in this area? If so the names and addresses of persons working in this related areas would be most helpful in our study.

I thank you in advance for your co-operation.

Yours very truly,
JACQUES, WHITFORD & ASSOCIATES LTD.

John A. Amirault, P. Eng.

APPENDIX 2.0.3

Optech Inc.

701 PETROLIA ROAD
DOWNSVIEW, ONTARIO, CANADA M3J 2N6
(416) 661-5904

January 27, 1983.

Mr. John A. Amirault, P. Eng.,
Jacques, Whitford and Associates Ltd.,
1046 Barrington St.,
Halifax, N.S. B3H 2R1

Dear Mr. Amirault: RE: Your Project No. M1237

Our company has been involved with the development of a variety of laser-based instruments for remote sensing. In our work we have analysed in some detail the techniques for measuring methane remotely. Although we have never addressed the problem from the specific requirements of coal mine safety, we have considered a number of applications involving both differential absorption measurements and Raman scattering. In fact, at present we are constructing for delivery to England a Raman system for methane detection which is capable of measuring low concentrations at distances up to one kilometer away. We would be able to construct a system to meet your needs if the requirements were more quantitatively specified.

Please do not hesitate to contact me if you wish further information.

Yours sincerely,

SS/ljh

S. Sizgoric,
General Manager.

OPTO-ELECTRONICS INC.

RESEARCH IN ELECTRO-OPTICS

January 13th, 1982.

John A. Amirault
Jacques, Whitford and Associates Ltd.,
1046 Barrington Street
Halifax, NS B3H 2R1

Dear Mr. Amirault:

I am writing in response to your letter of December 13th to Dr. J. Reid, who is a colleague of mine at McMaster University, but has no connection with Opto-Electronics Inc. There is a project currently underway at Opto-Electronics which is directed towards applications of the type you described. This project is concerned with the development of optical monitoring systems based on pulsed, tunable diode lasers. I have extracted below parts of the original proposal, which should give a reasonably good idea of what we are doing.

Continuous monitoring of gas concentrations can generally be performed best using optical techniques in which the gas or gases in question are detected through their infra-red absorption signatures. This approach can be used both for long path air monitoring on a single or multi-pass basis or within a specific environment to obtain average values for particular gas concentrations. Alternately, a sampling scheme can be used to obtain concentrations of the gases of interest at specific points. Unsurpassed specificity and concentration levels for gases have been achieved using low-pressure sample cell in conjunction with a tunable diode laser by a group from the Air Pollution Laboratory at McMaster University in Hamilton, Ontario. This laser absorption spectrometer (LAS), combines the sensitivity of the acousto-optical methods with the convenience of direct, long-path optical detection. In order to make the system as flexible as possible, it is based on wavelength-tunable Pb-salt diode lasers, which can be tailored to emit tunable radiation at wavelengths from 3 to 30 μm. The beam from a diode laser is passed through a multi-pass White cell before detection.

Pathlengths from 1 to 30 μm have been used in the system which is sensitive to absorption coefficients as small as $3 \times 10^{-8}\ m^{-1}$. This sensitivity is two or three orders of magnitude greater than that attained by previous direct optical techniques.

We plan to exploit the capabilities of the tunable diode systems by operating these lasers in a low average power, relatively high peak power mode. This approach is intended to dramatically reduce the very stringent electronic and thermal requirements necessary in the operation of presently available cw laser diode dystems in the 10-40°K region. Operation in a pulsed mode makes utilisation of higher base temperatures possible and permits very low average power (input and output) to be achieved. In this way, the demands on the diode laser cooling system are drastically reduced. In addition, the need for very precise (millidegree) diode laser temperature control is eliminated. Also, operation in a pulsed, low duty cycle mode allows relatively high peak powers to be employed which reduces the demands on the detection system. The many trade-offs between laser output power and pulselength, detection system requirements, laser tuning rate, system sensitivity etc. are currently being established. It is anticipated that gas concentrations on the scale of 1 ppm (part per million) will be achieved without difficulty. In this regard, some initial work by the McMaster group concerning atmospheric pressure measurement of SO_2 is encouraging. A continuously wavelength modulated laser diode is used over a range in which an absorption line of SO_2 occurs. Then many such wavelength scans are stored over a period of a few seconds to determine the strength of the SO_2 absorption. In this way, even at this preliminary stage, concentrations of a few parts per billion over a pathlength of hundreds of metres has been achieved with this rather weakly absorbing gas. Thus, scaling to shorter pathlengths should easily permit concentrations in the ppm range to be measured.

Applications of an absorption monitoring system of the above type encompass a wide range of process and hazard control and industrial safety uses. Examples are detecting leakage of noxious gases which may be employed in an industrial processing plant, and the continuous monitoring of specific reactants or process products in a chemical processing system. In this way, measurements can be made of combustion gas species concentration as well as temperatures in, for example, internal combustion engines, stack gas monitoring as applied, for example in power stations and pulp and paper processing, at the coal face in underground mines, in remote chemical process and radio-isotope monitoring.

Please don't hesistate to contact me if you need any further information.

Yours sincerely,

Brian Garside

Dr. Brian K. Garside
President

:lm

MONITEQ

Monitoring Environmental Quality
Moniteq Ltd., 630 Rivermede Road, Concord, Ontario, Canada L4K 1B6 (416) 669-5334 Telex: 06-964776

December 14, 1982

Mr. John A. Amirault
Jacques, Whitford and Associates Ltd.
Consulting Geotechnical and Materials Engineers
1046 Barrington Street
Halifax, Nova Scotia
B3H 2R1

Dear Mr. Amirault:

Please find enclosed a description of our GASPILS sensor development for the remote detection of methane and ethane. This sensor has been successfully field tested this month, in a helicopter mounted, downward looking mode of operation.

The sensor can be configured to sense such high concentrations as 1.5% of methane by making modifications to the device. In fact the operating path length would need to be better defined, but I expect the sensor could be operated with two spectral isolation filters instead of gas cells, and a modulated IR source reflecting from the mine walls might be used instead of relying on an unknown thermal difference between gas and background.

We believe our sensor and its level of development are of great potential to the problem your study poses. Should you require further discussion please contact us at the above-mentioned number, or a better arrangement would be to visit MONITEQ and discuss the method with the various people involved in this sensor development.

Yours sincerely,
MONITEQ Ltd.

H.H. Zwick, Ph.D.
Vice President
Technology

HHZ/sl
Encls.

cc. Dr. H.S. Lee, MONITEQ

QUANTITATIVE REMOTE SENSING TOOLS FOR AIR AND SURFACE MEASUREMENTS

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ABSTRACT

MONITEQ has been actively engaged in the development of several remote sensing instruments whose intent is to provide tools useful to quantitatively characterize the environment remotely from air and ground based platforms. These sensors are intended for measurements both of air quality and surface characteristics.

Three sensors are presented which have been developed and tested, two for atmospheric trace gas detection and one for surface spectral measurements. These measurements are quite different in nature and place different design requirements on the hardware.

1. SENSOR DETECTION OBJECTIVES

In the case of atmospheric trace gas detection by remote sensing, a suitable gas characteristic must be detected. We confine the discussion to the "optical" spectral region and leave aside radio, microwave and other regions as our objective is to develop portable, low cost and low power sensors, capable of making measurements in a dynamic environment. Aside from the hardware constraints, the measurements to be remotely made do not normally allow the placement of artificial sources, so that the measurements must be made with passive (natural solar or terrestrial) radiation. Configuration constraints for the sensors leave scattered skylight and earth surfaces radiance (reflected solar and thermal emission) as the energy source from which the measurements result. The gas characteristics available within the above constraints are the molecular electronic and vibration - rotation absorption and emission features.

The total amount of energy absorbed or emitted is small because trace gases must be detected at very low concentrations and the background radiation against which this is to be detected is large.

The above requirements demand sensors with spectral multiplexing, good light gathering capability, accurate signal processing and rapid response. Two separate gas sensors are described here, along with a sensor designed to accurately measure and record detailed spectral scans of land, vegetation, water and atmospheric sources.

2. PLUMETRACKER

2.1 Synopsis

This instrument is used from a mobile, ground or air based platform for the remote detection of SO_2 and NO_2 gas plumes resulting from utilities, smelters or refineries. The gases are detected by their absorption of scattered solar ultraviolet radiation by looking upward through the plume at the day sky. Interferent absorption from other gases are avoided by careful selection of the wavelengths of the measurement absorption peaks and also by the use of modulation spectroscopy. The instrument is shown in Figure 1.

2.2 Instrument Detail

The main components of the instrument are a light gathering telescope, a grating spectrometer with multiple exit slits, a slit aperture mask, detectors, and signal processing electronics. In addition, there are the calibration items, operator panel, and data reduction software. These are discussed in turn.

Light is collected in a 60 mrad by 1.6 mrad field of view by a demountable telescope at the front of the instrument. A 45° mirror folds the beam into the horizontally aligned instrument so that the sky above is viewed. This light enters the heart of the instrument, the grating spectrometer. Exit slits select the wavelengths for the two target gases, but instead of the normal one slit per gas, two per gas are used in Plumetracker. These are arranged to monitor on adjacent maximum and minimum in the absorption spectrum. A rotating aperture mask alternately passes the light from each slit onto a photomultiplier. Since two mask patterns and two photomultipliers are used, two gases can be monitored simultaneously. The optical train is shown schematically in Figure 2.

The process of sequencing through the acquisition of signal amplitudes at wavelengths on and off peak absorption is called modulation spectroscopy. In this manner, light at wavelengths of adjacent maximum and minimum absorption of the target gas is monitored alternately, resulting in a time modulated signal when there is gas in the field of view. When there is no gas, there is no difference signal because the source sky irradiance is the same at the different slit wavelengths. The amplitude of the modulated signal is therefore proportional to the column density of the gas along the sensor line of sight, which for pollutants is normally optically thin.

Interference from gases other than the target gases can only occur if they too have strongly differing absorption coefficients at the two chosen wavelengths. Oxygen and ozone are the principal gases with sufficient concentration and band structure in the ultraviolet to be considered a problem, but their main bands are below the 250 nm region whereas both SO_2 and NO_2 have band structures from 200 to 400 nm. The near UV region, then, avoids the O_2 and O_3 interferences and also provides a brighter sky radiation source which enhances the target gas detectability.

The optimum region to achieve good sensitivity to the target gases (SO_2 and NO_2), rejection of interferents, and adequate sky brightness is 310 nm for SO_2 and 430 nm for NO_2. This is also a convenient spectral region from the point of availability of optical components and detectors.

The signals from the photodetectors are processed by analog electronics to provide a voltage proportional to the gas concentration pathlength product. Phase sensitive detection synchronous with the aperture mask reduces the detector noise bandwidth, while an automatic gain control network ensures that variations in sky brightness with time or passage of clouds is compensated.

The instrument is calibrated over its dynamic range and a single point check capability is built into the instrument. This is achieved by blocking the skylight, activating the internal quartz iodine lamp, inserting a cell containing a known quantity of the target gas into the optical path before the spectrometer and recording the resulting output signal. All this is accomplished using two switches and the LCD on the instrument panel. Remote operation is also available.

Signal output appears both on the LCD on the panel and on an IEEE488 bus which is compatible with an HP85 desk top computer. Software developed by MONITEQ for this computer permits both data logging and calculation of mass flux and the dispersion properties of the plume.

In operation, the Plumetracker is hand portable being similar in size to a small oscilloscope, and is rugged and reliable. It can be run from a small invertor for mobile field measurements. The specifications of the Plumetracker are shown in Table 1.

TABLE 1

Plumetracker Specifications

Application:	remote detection of both SO_2 and NO_2 simultaneously
Detection Sensitivity:	2 ppm.m
Gas Detection:	dynamic range: 1000 ppm.m
Calibration:	internal quartz iodine lamp and sealed absorption cell
Physical:	Size: 20.5 x 28.5 x 69 cm Weight: 16 kg Power: 110V, 60Hz, 150W
Output:	LCD panel display and interface to HP85
Analysis Software:	built in software for HP85 to determine mass flux and plume dispersion parameters

methane centred at a 7.8 micrometre wavelength, and one train for ethane with a spectral filter centred at 12.2 micrometres.

The measurement of leak gas signal is formed by computing the difference between the gain adjusted electrical signal derived when a neutral gas filter is in the optical train compared with the signal resulting when a sample cell of the leak gas is rotated into position in the light path in front of the field stop. The chopper disc alternately places such a reference and leak gas cell in the field of view and digital synchronous signal processing averages the estimate of signal present in the sensor line of sight.

The GASPILS sensor electronics are designed to handle the signals in a manner which computes the small difference signal, either from absorption or thermal emission, due to the presence of the leak gas signature in the incoming light, and to temporally extrapolate the signals to compensate for time rate of change effects as radiant hot spots pass through the sensor field of view. The use of a Z-80 based microcomputer permits signal averaging, gain adjustment to balance the sensor in the absence of leak gas, deal with two sets of optical signals (methane and ethane), and format the output signals with estimates of the quantity of gas in the line of sight as well as estimates of the surface radiant temperature at each wavelength.

The sensor package is illustrated in Figure 6. The laboratory test results of this sensor indicate the specifications listed in Table 2.

TABLE 2

GASPILS Specifications

Detection Limits:	(dependent on the earth surface emissivity ε_e, the blackbody temperature of the earth $\bar{B}_e$, and the gas $\bar{B}_a$; typical values are given below)	
	CH_4:	50 ppm.M (7.8 microns)
	C_2H_6:	9 ppm.M (12.2 microns)
Signal Output:	(a)	0-10 volt analog (CH_4, C_2H_6)
	(b)	RS-232, 7 bit ASCII at 300 baud
Power:	28VDC	200 Watts startup 150 Watts operating
Size:	30 x 45 - 60 cm	
Weight:	25 kgm	

2.3 Performance

Figure 3 shows the plume profile recorded 2.8 km downwind from a thermal electricity generating station in the Toronto area. The peak amplitude is about half the instrument's dynamic range. At 7.5 km, the plume is still clearly visible with a S/N ≈ 5 despite the broad dispersion at that distance. Figure 4 shows the HP85 printout from the plume model.

2.4 Future Work

In its present configuration the instrument is used primarily as a tool for locating airborne plumes of SO_2 and NO_2 and tracking these plumes while they remain aloft. Quantitative integrated measurements are thus available as additive and incremental over the normal integrated sky background. This limitation does not detract from the capability of the Plumetracker to provide quantitative data on mass emission and plume dispersion parameters. Currently, work is underway to quantify this background effect and provide absolute SO_2 overburden measurements. This data is required for trans-boundary flow and long range transport model verification. The approach being pursued allows a more flexible method to correct for skylight variations, the major difficulty in making absolute overburden measurements. The model when proven will be accessible through the HP85.

3. GAS PIPELINE LEAK SENSOR (GASPILS)

3.1 Introduction

GASPILS is a passive electro-optical sensor designed to detect the leak gas (methane and ethane) from natural gas pipelines. The instrument detects these leak gases by sensing the infrared spectral radiation (absorption or emission) due to their spectral signatures against the earth's surface background radiation. The instrument is able to detect small spectral changes due to the gases through the use of a Gas Filter Correlation (GFC) technique. In this type of sensor the amount of specific gas present in a particular spectral band structure is measured by the difference in signal resulting when passing the incoming light alternately through a spectrally neutral filter, and a matched filter achieved with a sample cell of the gas to be sensed. The instrument is designed to be flown along gas pipelines in the downward looking mode and signals an alarm when there is a combined increase in the amount of methane and ethane in the atmosphere at a leak site.

3.2 Sensor Description

The optical schematic of the GASPILS sensor is shown in Figure 5. Incoming light is collected by the telescope lens and passed through the gas cell chopper wheel and a field defining aperture before being relayed, spectrally filtered by a band limiting interference filter, and passed via the collector lens onto a cryogenically cooled infrared detector. GASPILS consists of two such optical trains, one for

4. A PROGRAMMABLE BAND RADIOMETER (PROBAR)

4.1 Introduction

PROBAR is a programmable band radiometer specifically designed for remote sensing applications in the 400 nm to 2.5 micrometre region. The sensor is field portable and is used to collect accurate spectral data of the earth's surface in the field for subsequent detailed computer analysis. The sensor has high spectral sensitivity and resolution, and wide radiometric dynamic range making possible the collection of data from agricultural, geological, forested or aquatic environments.

The spectral bands of the radiometer may be programmed to match those of interest to the user. The 400 to 1000 nm region bands are electronically programmable while those in the 1.3 to 2.5 micrometre region may be modified through mechanical changes.

PROBAR is designed to collect upwelling reflected solar radiance from the direction in which the instrument is sighted. A self-leveling irradiance diffuser attachment and internal rotating sector disc alternately direct light into the sensor from the direction of sight, downwelling irradiance and dark current. Thus, PROBAR collects all the data needed for precise field reflectance spectroscopy, and hence is valuable for studying field spectral characteristics.

4.2 Optical-Mechanical Description

An optical schematic of PROBAR is shown in Figure 7. The sensor is intended to be tripod mounted and may be sighted to point at the surface of interest by means of a viewing sight built into the instrument. A three sector chopper disc then directs into the sensor: (a) upwelling radiance from the line of sight, (b) downwelling (direct solar and diffuse sky) irradiance from the opal diffuser attachment, or (c) a dark sector blocking all incoming light and providing dark current measurement. The chopper disc rotates once every two seconds so that the field illumination conditions remain constant during the data collection. Many data samples are gathered during each chopper sector and over several rotations for precise data averaging.

The radiance field of view may be selected by the operator to be either 1 or 15 degrees. The large field is intended primarily for surveying crop canopies with sufficient spatial integration to avoid shadow effects from individual plants and leaves, while the 1 degree field of view is provided primarily for solar extinction measurements. Solar measurements must have narrow fields of view so as to minimize forward scattering in the atmosphere, while at the same time providing sufficient operator ease in alignment on the solar disc. The 1 degree size is the best compromise for these competing effects. Neutral density filters are provided to protect the detectors from direct sun exposure and to extend the dynamic range for the flux levels associated with solar observations.

The central optical feature of PROBAR is an Ebert prism spectrograph which uses a single entrance slit and two detectors in the exit plane to cover the required spectral range. A linear 128 element array of silicon photodiodes gives continuous coverage between 400 and 1100 nm, while a single lead sulfide detector alternately measures flux in the two near infrared Thematic Mapper Bands 1550 to 1750 nm and 2080 to 2350 nm. PROBAR is illustrated in Figure 8.

4.3 Data Collection

Data is acquired in one hundred and thirty spectral channels during readout of the array and lead sulfide detectors. These measurements are repetitively made in each sector of the chopper. Data is averaged, corrected for offset, and stored in appropriate buffers and averaged over several rotations. A calibration PROM contains the radiometric calibration factors for each channel.

During a given measurement up to sixteen spectral bands may be selected. No limitations are placed on the wavelengths of the band edges - that is, bands may be disjoint or overlapping. The bands incorporated most commonly are three sets of pre-programmed bands, Landsat MultiSpectral Scanner, Coastal Zone Colour Scanner, and Thematic Mapper. The operator may determine, via the control panel, the band selection to be used during data acquisition.

During band selection and radiometric correction, the average spectral radiance (and irradiance) is calculated within each band and the results are stored in a display buffer, for either display or data logging.

Four modes of operation have been pre-programmed. In the normal mode data is averaged over 32 revolutions of the selector disc. However, a peak mode is provided to measure solar irradiance from a moving platform. In this mode, data is averaged over each chopper revolution and a set of 16 revolutions is examined for peak value which is then buffered for display or data logging. In addition to these modes, a rocker selector switch allows the operator to set the instrument to a triggered or free running mode. Free running operation is intended to use during set up giving an updated display every 4 seconds. The triggered mode of operation is used during a field survey for data acquisition and logging when a remote start button is depressed. The acquisition and logging functions may be separated and the acquired data is available for examination both before and after the logging operation.

4.4 Calibration

PROBAR has been calibrated in wavelengths and intensity to a quartz iodine lamp and barium sulphate panel. In addition, PROBAR has an operating mode intended for use as a calibration check where all 130 channels may be logged without radiometric calibration factors. This operation is intended to allow the operator to set up a calibration experiment, and to log calibration data to assure himself of satisfactory operation, or to establish new calibration factors, which may

be placed into EPROM. Time is automatically logged into the data stream with the field data.

4.5 Data Analysis

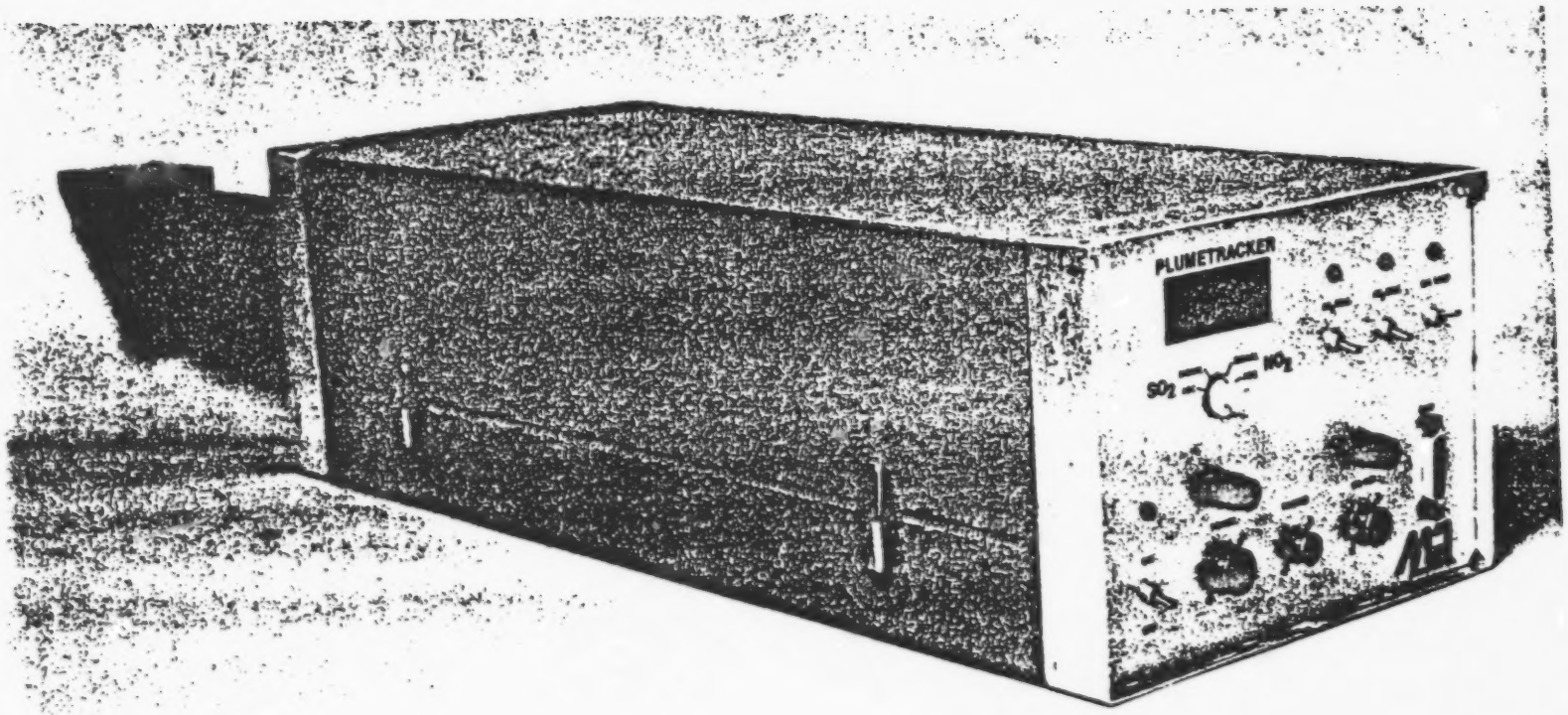
The TU58 magnetic tape data logger permits the operator, after logging all of the radiance and irradiance data in the field, to enter the data into a computer for analysis. Software is supplied for PROBAR data base management and editing. This software also prompts the operator for geographical and other information and subsequently computes several atmospheric parameters from measured solar data, e.g., nadir looking path radiance (from 400 to 2500 nm) which would be expected to be seen by an overhead satellite, and the aerosol optical depth of the atmosphere (400 to 2500 nm). The PROBAR specifications are summarized in Table 3.

TABLE 3

PROBAR Specifications

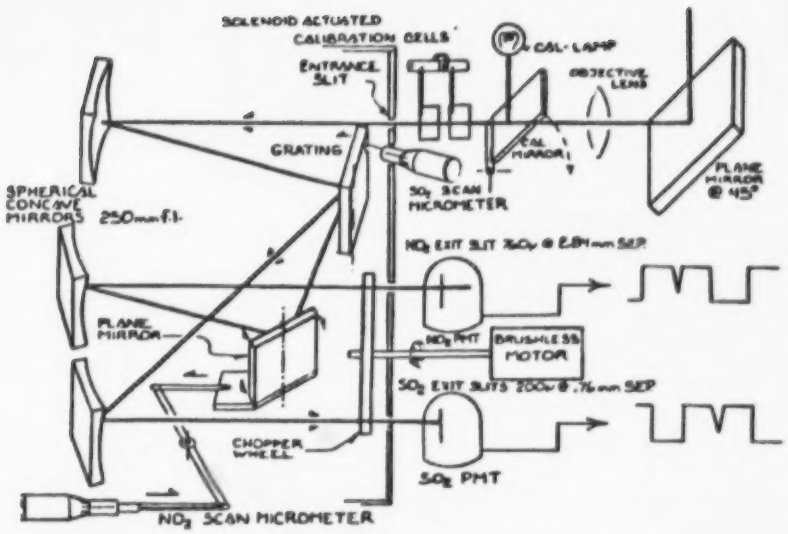
Spectral Range:	400 to 2500 nm
Radiance Range:	(400 to 800 nm) 10^{-8} to 5×10^{-5} $Wcm^{-2}sr^{-1}nm^{-1}$ (2300 nm) 2×10^{-8} to 8×10^{-6} $Wcm^{-2}sr^{-1}nm^{-1}$
Irradiance Range:	1 to 4 airmass units
Solar Beam:	1 to 4 airmass units
Typical Band Sets: (Micrometres)	Landsat MSS .5-.6, .6-.7, .7-.8, .8-1.1 CZCS .433-.453, .510-.530, .540-.560, .660-.680, .700-.800 Thematic Mapper .45-.52, .52-.60, .63-.69, .76-.90, 1.55-1.75, 2.08-2.35
Physical:	Size: 45 x 45 x 60 cms Weight: <20 kg Power: 12VDC, 8A FOV: 1° or 15° Output: LED or TU58

FIGURE 1



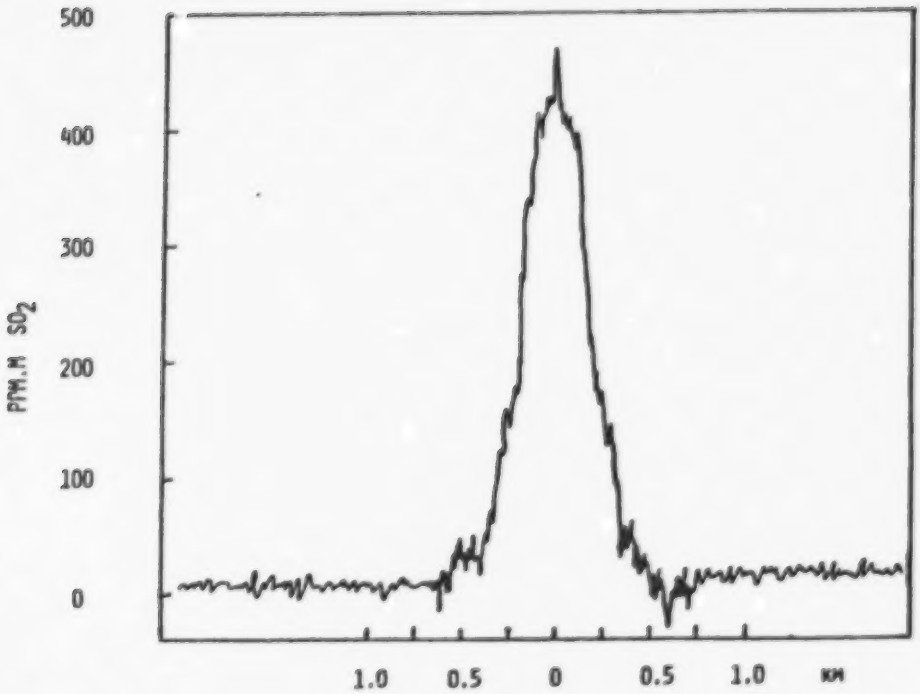
Plumetracker sensor. This instrument is designed for the remote detection of trace quantities of SO_2 and NO_2 in the atmosphere.

FIGURE 2



Optical schematic of Plumetracker. The illustration shows the path followed by atmospheric radiation as it passes through the receiving telescope lens, through the modulation spectrometer and falls on the phototube detector. Signal processing is done in the electronics to synchronously detect the very small modulated trace gas absorption signal.

FIGURE 3

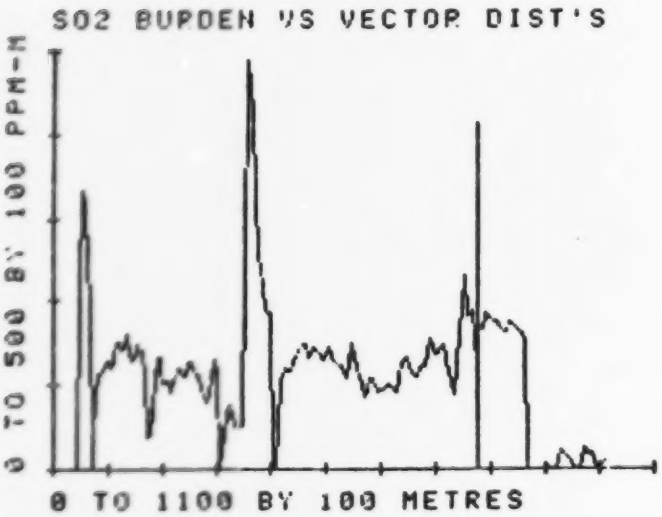


Field operational results obtained with the Plumetracker operating in an upward looking mode and traversing an SO_2 plume from a thermal generating system.

FIGURE 4

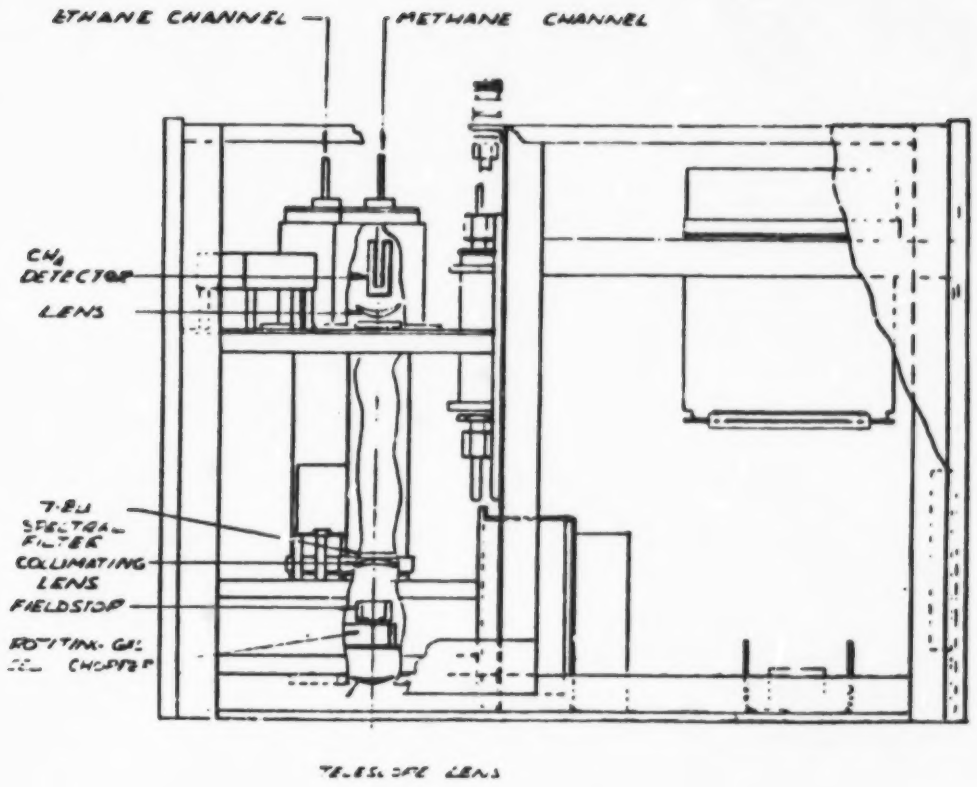
SO2 DATA
ON DAY 203 RUN 1
WIND SPEED = 25 M/SEC
WIND DIRECTION= 270 DEG E OF N
CAL FACTOR = 131.6 PPMM/V
MASS FLUX = 7.42 KG/SEC
CENTRE OF MASS= 515 METRES
DISPERSION = 547 METRES
PEAK MASS = 488.2 PPM-M
LOCATION = 356 METRES

(STATISTICS ARE FOR VECTOR
DISTANCES PERPENDICULAR TO
WIND DIRECTION)



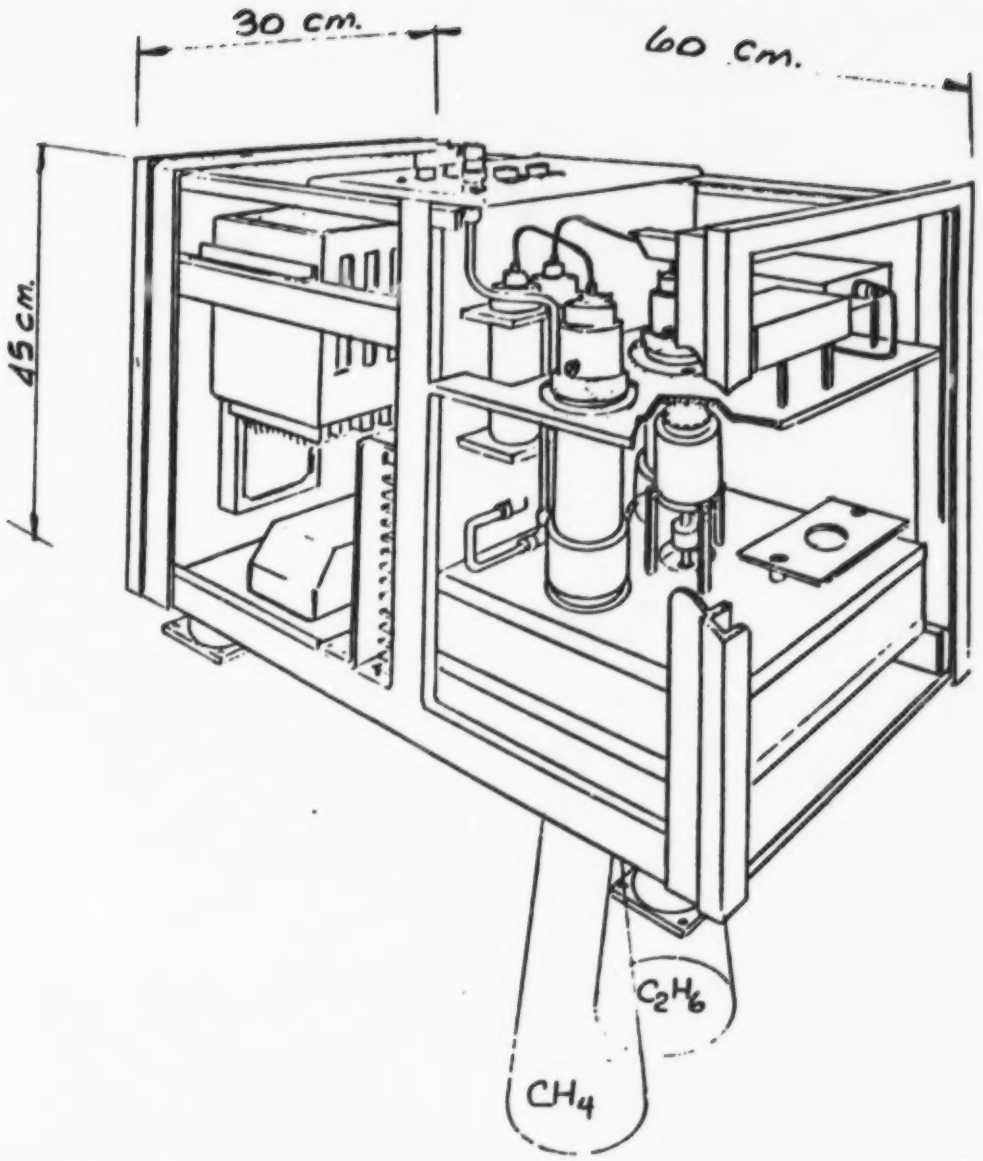
The computer printout of Plumetracker data following on-line analysis in the HP85 data logging and analysis system.

FIGURE 5



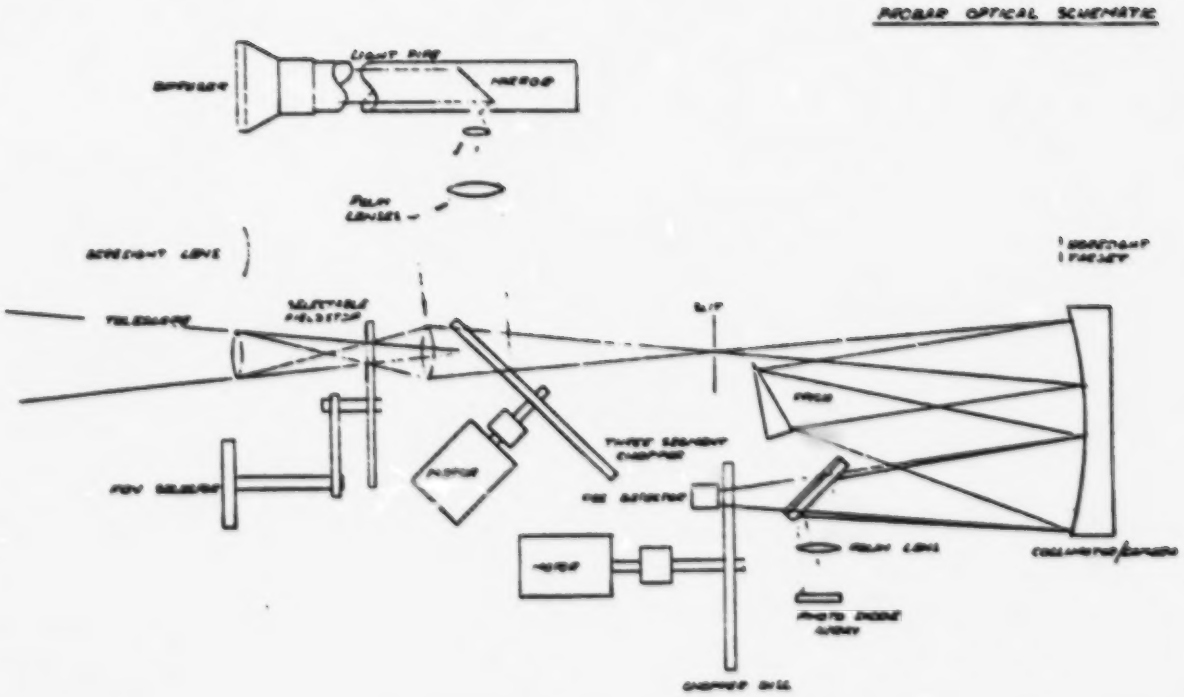
The optical schematic of the GASPILS sensor. This device is designed for downward looking while flying along pipeline routes to detect natural gas leaks. Light passes through the telescope lens and the spectrally matched gas cell filter chopper wheel, and then on to the detectors. Signal averaging and processing is done using a micro-computer based signal processing electronics package.

FIGURE 6



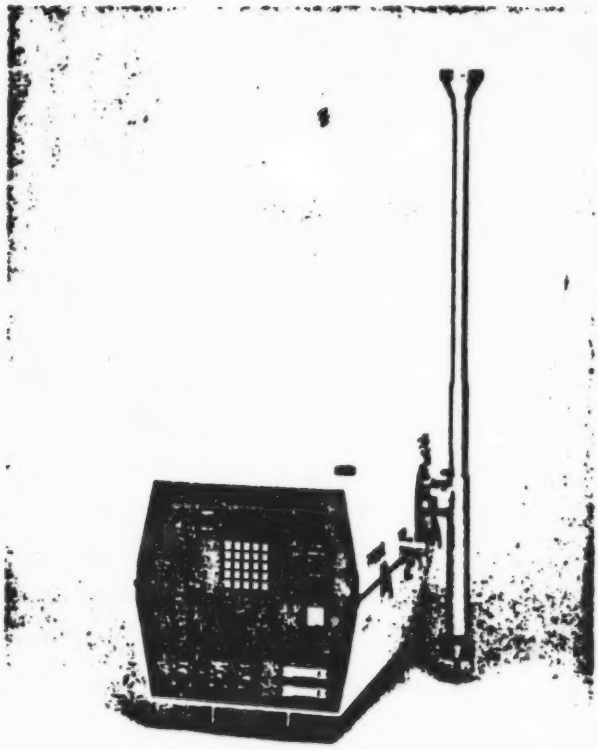
The GASPILS sensor configuration. The two optical beams (CH_4 at 7.8 micrometres and C_2H_6 at 12.2 micrometres) look downward from the airborne platform to intercept leak gas plumes as they are traversed by the moving footprint.

FIGURE 7



The optical schematic of the PROBAR sensor. Light entering the PROBAR telescope is dispersed by the prism spectrograph, and divided to a 128 element photodiode array and a PbS detector. Signal processing, display, formatting and output to magnetic tape is under the control of a Z-80 based microprocessor system.

FIGURE 8



A photographic presentation of PROBAR, a device for the remote near surface study of land, water and vegetated surfaces.

GAS PIPELINE LEAK SENSOR (GASPILS) December 6, 1982

Introduction

The Gas Pipeline Leak Sensor (GASPILS) is shown in Figure 1. GASPILS is a passive electro-optical sensor designed to remotely detect the leak gas (methane and ethane) from natural gas pipelines. The instrument detects these leak gases by sensing the infrared spectral radiation (absorption or emission) due to their spectral signatures against the earth's surface background radiation. The instrument is able to detect small spectral changes due to the presence of these gases through the use of a Gas Filter Correlation (GFC) technique illustrated in Figure 2b. In this type of sensor the amount of trace gas present in a particular spectral band is measured by the difference in signal resulting when passing the incoming light alternately through a spectrally neutral filter, and a matched filter achieved with a sample cell of the gas to be sensed. The signal passing through these two cells is precisely measured, and subsequently balanced electronically to be the same when no trace gas signal is present in the incoming light. This balance condition is then upset by the presence of the trace gas in spectral absorption or emission in the incoming light. The GASPILS is designed to be flown along gas pipelines in the downward looking mode and signals an alarm when there is a combined increase in the amount of methane and ethane in the atmosphere at a leak site. The most significant advantage of the airborne gas sensor when compared with traditional surveying methods is cost savings. Great lengths of pipelines can be surveyed each day.

Sensor Description

(a) Optical

The GASPILS sensor schematic is shown in Figure 2a. Incoming light is collected by the telescope lens and passed through the gas cell chopper wheel and a field defining aperture before being relayed, spectrally filtered

by a band limiting interference filter, and transmitted via the collector lens onto a cryogenically cooled infrared detector. GASPILS consists of two such optical trains, one for methane with a spectral filter centred at 7.8 micrometre wavelength, and one for ethane with a spectral filter centred at 12.2 micrometres.

The optical chopper disc located in front of the field stop alternately places a cell of the leak gas and a spectrally neutral reference cell into the sensor field of view. The measurement of the presence of leak gas signal in the incoming light is made by accurately computing the difference between the (gain balanced) electrical signal derived when the two filter cells are placed in the optical train (Figure 2b).

(b) Electronics

The GASPILS sensor electronics are designed to handle the signals in the manner which computes the small difference signal, either from absorption or thermal emission, due to the presence of the leak gas signature in the incoming light. Digital synchronous signal processing averages the estimate of signal present in the sensor line of sight from each cell, and computes the gain balanced difference signal. The digital processing also temporally interpolates the signal from each cell to compensate for time rate of change effects as radiant hot spots pass through the sensor field of view. The use of a Z-80 based micro-computer permits signal averaging, gain adjustment to balance the sensor in the absence of leak gas, deals with two sets of optical signals (methane and ethane), and formats the output signals with estimates of the quantity of gas in the line of sight as well as estimates of the surface radiance at each wavelength.

(c) Present Status

The sensor has undergone detailed design, fabrication, assembly and complete laboratory testing. Initial helicopter based tests have taken place and to date GASPILS has performed extremely well. Several areas for even better

performance have been identified for future improvements. The laboratory test results of the present sensor result in the specifications listed in Table 1.

Field Application

(a) Downward Looking Remote Leak Surveillance.

The GASPILS sensor has been designed to operate from the rigorous operating conditions imposed on a downward looking sensor based on a moving airborne platform. This has caused the sensor to be designed to have immunity from changing radiance levels due to thermal and surface characteristic differences as the sensor footprint moves over the surface. The sensor is designed to detect CH_4 and C_2H_6; however small sensor configuration changes cause the sensor to be sensitive (and specific) to a wide range of other gases (e.g. CO, SF_6, SO_2, N_2O, NH_3, Ethylene, Organophosphates, etc.). The sensor may be used as a stand alone device or in combination with other sensors. In addition, it may find leaks directly or potential leak sites which can be validated through specific site ground validation.

(b) Upward Looking Remote Detection

The sensor can be surface (or vehicle) mounted and pointed upward to sense the thermal emission from the same wide range of gases described above. In this mode the trace gas thermal emission is sensed against the cold sky background. The same design features which are incorporated for operating mode (a) are useful to allow the sensor to operate in the presence of variable cloud cover.

(c) Fixed Location Monitoring Gaspils has applications for surveillance of a range of specific gases. e.g. Petrochemical Complexes, Landfill Sites, Refineries, etc.

(i) Long Path. GASPILS can be mounted to monitor a selected path (linear path or a perimeter monitor using mirrors) by pointing the sensor at a known source. In this mode the sensor is capable of continuous monitoring of a strategic location for preselected gases. In this mode the detection limits are expected to be better than in the case of remote measurements due to the greater thermal contrast between the artificial source and the absorbing gas.

(ii) Ambient In-Situ Monitoring. The sensor can also be operated as an in-situ or ambient monitor, with high sensitivity and speed of response. In this case the sample gas is pumped or allowed to flow through a known path within the sensor and the concentration of the trace gas content monitored. Through use of a high temperature source, the detection limits may be much better than those possible using a natural source.

Airborne Operation

(a) Signal Interpretation

The GASPILS sensor monitors the integrated amount of trace gas along the line of sight, with a sensitivity which depends on the thermal contrast between the gas and the background.

In the "real world" the atmosphere-surface thermal contrast is variable, in part due to air thermal variations, but primarily due to thermal variations in the surface radiant termperature. Methane is present naturally in the atomosphere, and thus the "natural background" signal may vary as the thermal contrast varies, or as the path length varies. This changing background signal must be distinguished from the signal due to gas leakage.

One solution to this is to monitor the radiant temperature of the surface as well as the gas signal, and to take these surface temperature changes into account in the signal processing of the "natural background" signal. This solution assumes a constant atmospheric temperature profile. The microprocessor based digital processing design of GASPILS has the built-in expansion capability to perform such computations in real time. This algorithm will be developed and installed during field trials. Another solution is to monitor a reference signal from another "background gas" which is assumed to be mixed in the atomosphere in the same way as the background amount of the trace gas of interest. Such a reference gas is found in N_2O and the conversion of one of the channels of GASPILS to monitor such a reference gas is easily achieved. In this case, the processing algorithms would be different, but simpler to implement in real time.

(b) Operating Conditions

GASPILS is expected to perform best at mid-morning, on sunny days when the surface radiant temperature has increased appreciably under solar heating, while the atmosphere has not yet reached unstable mixing conditions. The reduction in performance from this anticipated optimum performance is expected to be slow because the atmospheric lapse rate is maintained under most conditions during the day. In fact the performance may well be better under conditions other than those anticipated above, and only experimental evidence will show the ideal conditions and the rate of reduction in performance when conditions degrade from ideal.

Summer conditions are expected to outperform winter conditions for two reasons. First, the thermal contrast between the surface (snow) and the atmosphere is expected to be smaller in winter, and second, as the ambient temperature decreases the detection sensitivity decreases, even at the same thermal contrast. This reduction in sensitivity with temperature can be placed in perspective in the following example. A fixed thermal contrast ($4^{\circ}C$) at 20°C ambient is expected to have approximately twice as good sensitivity to methane as the same ($4^{\circ}C$) contrast at -20°C ambient.

(c) Supplementary Airborne Sensors

Operational monitoring normally performs best with a suite of sensors which complement each other. GASPILS is expected to perform well on its own as a leak gas alarm indicator once the data reduction methodology has been established. Nevertheless, the value of the remote sensor (and other) data is enhanced when combined with data from auxiliary sensors.

A potentially valuable auxiliary data source to supplement GASPILS data is that from a thermal imager. A thermal imager detects thermal change, just as the radiance output of GASPILS does, but in addition thermal imagery can provide information on the grade conditions, third party activity (digging, etc.), changes in the condition of the terrain due to effects other than leaks, etc. Thermal imagers, operating in a television fashion, are readily available from several suppliers at moderate cost. Some very high quality thermal imagers also are available.

(d) Calibration

Balance (zero gas) - In order to verify that GASPILS is correctly balanced, an infrared extended source is placed in the field of view of the sensor. Electronic gain adjustment is carried out while observing two separate source temperatures, until the balance condition is maintained while the source temperature is adjusted between the extremes.

Span - A one-half metre sample cell with appropriate infrared transmitting windows is placed between the sensor and the extended source. Known amounts of gas are introduced into the cell and calibration curves obtained under specific operating conditions. (Range of expected environmental source and gas cell temperatures.)

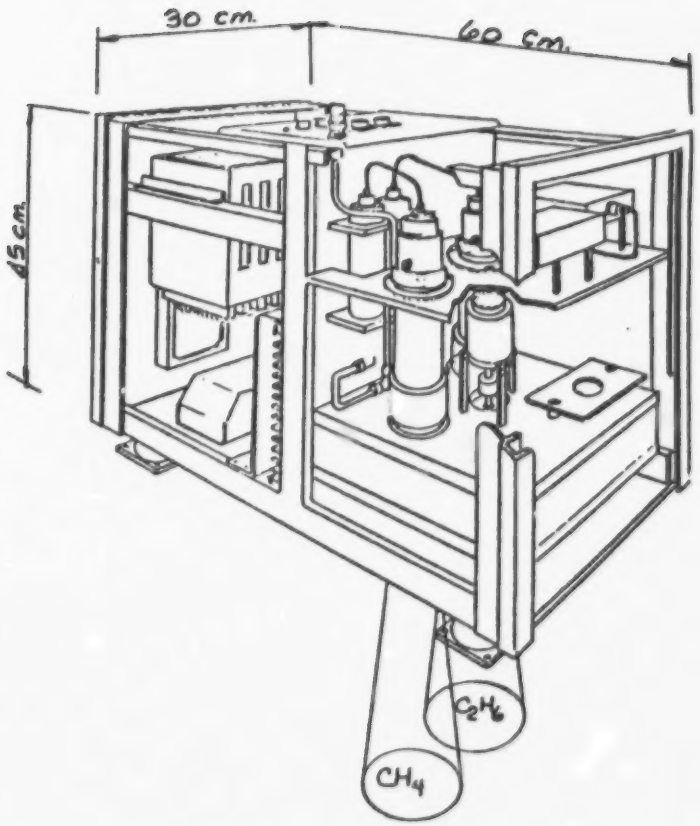
TABLE 1

GASPILS Prototype Specifications

Detection Limits:	(dependent on the earth surface emissivity ε the blackbody temperature of the earth $\bar{B}_e$, and the gas B_a; example values are given below)
	CH_4: 70 ppm.M (7.8 microns) at $\Delta T = 4^{\circ}C$, $\varepsilon_e = 1$.
	C_2H_6: 750 ppm.M (12.2 microns) at $\Delta T = 4^{\circ}C$ $\varepsilon_e = 1$.
Signal Output:	(a) 0-10 volt analog gas signals, radiance signals for CH_4, C_2H_6 and the ratio of gas signals.
	(b) RS-232, 7 bit ASCII at 300 baud for the same signals as above.
Power:	28VDC 200 Watts startup 150 Watts operating
Size:	30 x 45 x 60 cm
Weight:	25 kgm

Future work will increase the ethane sensitivity and reduce sensor size.

FIGURE 1



GASPILS

FIGURE 2

(a) GASPILS operates as a non-dispersive analyzer using the gas filter correlation technique.

(b) Shows the spectral transmission characteristics of reference and gas cells which are alternately placed into the optical path within the sensor. The radiance passing through the reference cell is sensitive and specific to the amount to gas signal in the incoming light, while the radiance passing through the gas cell is not changed by the presence of gas signal in the incoming light.

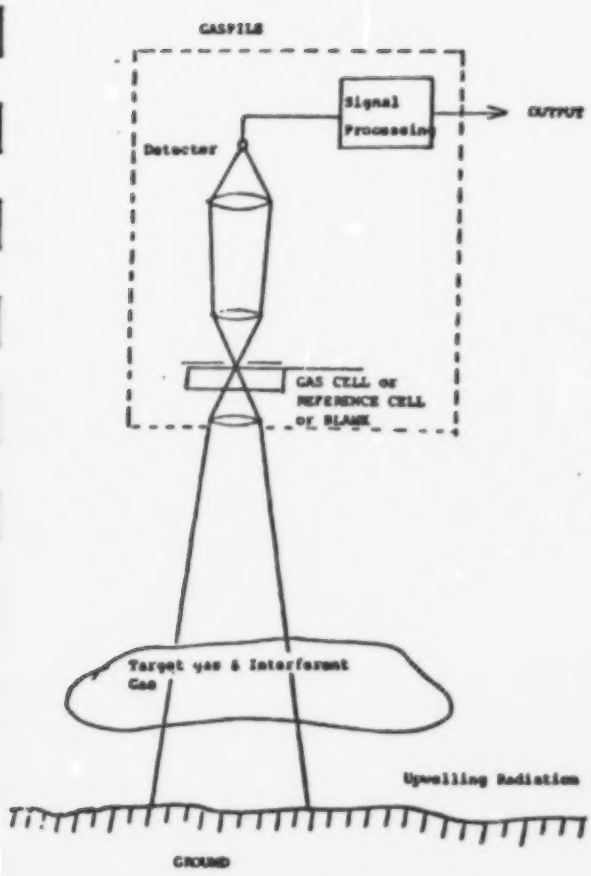


FIGURE 2(a)

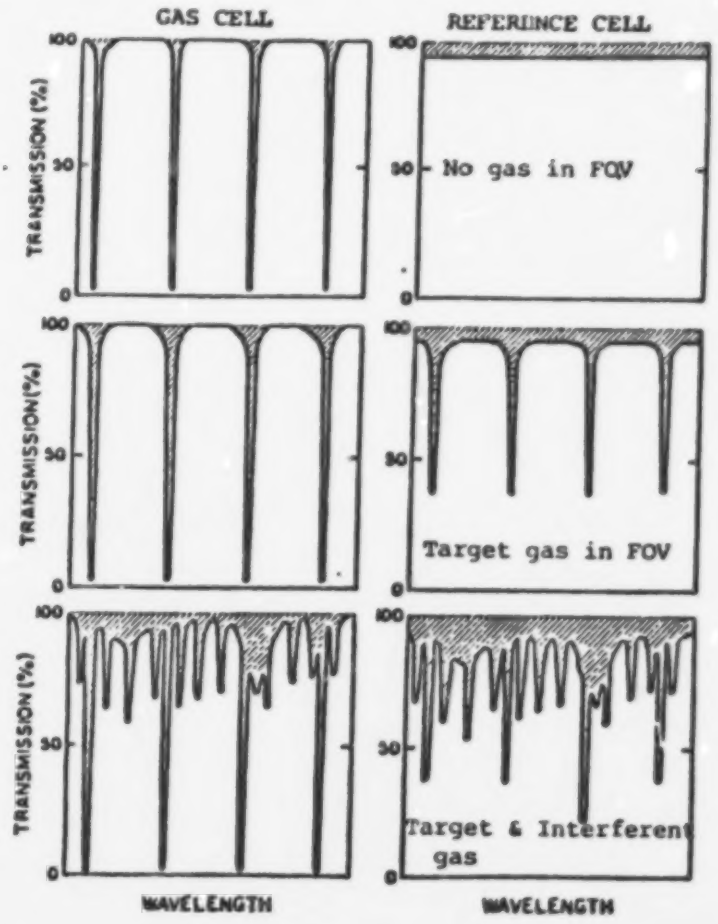


FIGURE 2(b)

GASPILS (Gas Spill Leak Sensor)

GASPILS Is an electro-optical sensor for the remote detection of atmospheric trace gases. Two versions are available as single or dual channel sensors. The sensors operate in the thermal spectral region and detect trace gases by sensing the small spectral radiance due to the gas emission or absorption against the earth's background radiation. The GASPILS sensor has been designed to operate in a downward or forward looking mode from an airborne platform.

Principle of Operation

GASPILS is a non-dispersive analyser, with the attendant high sensitivity (good light gathering capability) and high specificity (senses the gases in the presence of large background spectral and radiance changes). The use of matched gas cell spectral filters of the gases to be sensed, provides these characteristics. A Z-80 based microprocessor performs a variety of data processing functions including signal averaging, balancing, normalization and formatting. The temporal variations in radiance as the sensor footprint moves over "hot spots" on the surface are successfully processed out by the firmware algorithms within the sensor.

Thermal infrared detection of atmospheric trace gas sensitivity is dependent on the trace gas optical characteristics and environmental contrast.

The detection limits of the sensor are given as the product of the intergrated trace gas concentration and its optical path in the sensor field of view.

(e.g. CH_4 = 70 ppm. Metre at 7.8 microns and $\Delta T = 4^{\circ}C$)

GASPILS SPECIFICATIONS

Functional

- Sensitivity - CH_4 = 70 ppm.M (7.8) at ΔT = 4°C
- Potential Trace Gases; e.g. CH_4, C_2H_4, C_2H_6, N_2O, SO_2, SF_6, Organophosphates (any gas with spectral signature in the thermal infrared)
- Simultaneous dual gas channel operation as an option
- Interferent rejection (> 5000:1)

Physical

- Size - 30 x 45 x 60 cm
- Weight - 25 kgm
- Power - 200 watts start up, 28 VDC
  (150 watts operating)
- Environmental - 0° to +40°C
  - flight tested

Output

- 0 - 10 VDC gas signal for each channel
- 0 - 10 VDC thermal radiance at each channel
- 0 - 10 VDC ratio of dual gas channel signals
- RS232 multiplexed 7 bit ASCII at 300 baud for each gas, radiance and dual gas ratio

TELEPHONE CONVERSATION RECORD

Person Called: J. Amirault
Person Calling: Mervyn Peatfield

Date: 31 Jan. 1983
Time: 1:00 pm
City: Houston, TX

Subject: G.P. Elliott
Remote Methane Detection

Items Discussed:

RE: My Telex

1. They are involved in Laser based systems in the 10-12 u range, for atmospheric CH_4, gas leaks.

   He will send TECH DETAILS on their system.

2. Recommends to Contact:

   Homer Research Lab
   Div. of Bethlehem Steel
   Pittsburgh, PA

   they have contracted:

   Dr. Richard Elliott (503) 645-1121
   Oregon Graduate Center
   Beaverton, ORE

   To develop diode laser 1.7u
   Expects announcement in May/FLA?

3. ERT are developing a Portable Methane Detector employing a HeNi Laser - California

   Reference:

   Jet Propalsion Laboratory
   Pasedena, California
   Mr. Bill Grout - (213) 354-2750

E A G L E

Elliott
Absorption
Gas
Laser
Equipment

A General Description and Application of a
Laser-Based Monitoring System

CONTENTS

SECTION 1	Introduction
SECTION 2	Operating Principles of the EAGLE Gas Detection System
SECTION 3	The Advantages of Using Laser Energy
SECTION 4	General Description of EAGLE System
SECTION 5	Specification of EAGLE System
SECTION 6	Examples of Gas Species Detected by Laser
SECTION 7	Applications For The Eagle Gas Laser System

GP-Elliott Electronic Systems, Inc., 1900 West Loop South, Suite 1460, Houston, Texas 77027. Telephone Number: (713) 626-9706. Telex Number: 774370 (GPE HOU)

EAGLE

ELLIOTT ABSORPTION GAS LASER EQUIPMENT

A Major Breakthrough in Gas Detection

A significant development in the field of environmental monitoring uses a scanning laser beam to measure the presence of gas in the atmosphere, or within an enclosure such as a duct or intake.

Whereas conventional single point gas detectors require the active ingression of gas into the detector, the EAGLE in scan mode, searches for gas and has a response time of 10 milliseconds for each unit of area covered. One EAGLE instrument does the work of many conventional detectors, and can provide information to fine tune processes and optimize use of raw materials.

Certain analytical instruments use the principle that gases absorb energy at specific wavelengths, the EAGLE extends this technique by using lasers. Two laser sources are employed, one operating at a wavelength absorbed by the gas to be detected and the other at a nearby wavelength not absorbed by the gas. Using the Differential Absorption Technique, comparison of the reflected energy provides an accurate measurement which is unaffected by temperature, pressure, reflecting properties and varying weather conditions.

SECTION 1: INTRODUCTION

Detection of combustible and toxic gases is required on petrochemical plants, offshore platforms, tankers, etc., to give an early warning of gas leaks so that action can be taken to prevent fire and explosion and protect lives and property. Fixed point sensors do not provide complete coverage of an installation, they require on-going maintenance to keep them fully operational and often the response times are insufficient to give a true progress report on a gas leak or cloud of vapour. Additionally, for control purposes, chromotography and spectroscopy do not often provide a fast response to optimize processes in power generation or bulk production processes such as steel manufacture.

The laser system detects the presence of gas with laser beams, utilizing infrared absorption. By scanning the beams, a majority of the plant can be surveyed to give a profile of a gas cloud with location and quantity. The system is fully fault supervised and may be made self-calibrating.

With the increasing focus on environmental monitoring and pollution control, the laser system is assured of an important place in this field, with its fast and comprehensive coverage capabilities. The system will also prove effective in optimization of energy resources and raw materials in manufacturing industry.

ICI, Ltd. has constructed an experimental system which has operated successfully in an 18 month period detecting ethylene gas in a polyethylene plant. These trials showed that the system overcame the disadvantages of point detectors. It provided general background information of gas around the plant permitting variations from the normal to be immediately identified. Detection levels down to 1.0 ppm or better are possible permitting the detection of leaks in open windy areas.

Experience with the equipment has shown that it is very effective in locating ethylene leaks. On some plants, the amount of ethylene lost each year through leaks exceeds 1,000 tons. At $500 a ton, this represents an annual loss of $500,000. It is confidently anticipated that the use of an EAGLE system will allow this to be reduced by 50%. From this source alone, therefore, the instrument will pay for itself in the first year of operation.

SECTION 2: OPERATING PRINCIPLES OF THE EAGLE GAS DETECTION SYSTEM

Most gases absorb infrared energy; infrared spectra reveal the wavelengths absorbed by a particular gas. Many analytical instruments employ this technique. A sample of the atmosphere is drawn into the analytical instrument and passed through a tube perhaps 10-20 cms. long. An infrared source (producing radiation at the wavelength absorbed by the gas to be detected) illuminates the tube and a detector at the far end of the tube determines the transmitted radiation. The technique is accurate and precise and for many gases accuracies better than ± 1.0 ppm can be achieved.

The use of lasers permits the detection of gases on-line. A laser operating at the required wavelength produces a beam which surveys the plant, the scattered radiation falls on a detector. The gas in the beam causes the signal at the detector to fall. Depending on species to be detected accuracies corresponding to ± 1.0 ppm or better can be achieved with response times of 10 milliseconds.

A full appreciation of the technique and its operation on ethylene gas can be obtained by reference to the idealized infrared spectra for ethylene and the simplified principle of operation (Figure 1). Infrared energy at 10.6 microns is absorbed by ethylene.

The instrument, as outlined in Figure 1 has a laser (laser A) radiating at 10.6 microns (the measurement wavelength), some of the scattered radiation is picked up by detector A.

A second laser (laser B) radiates infrared radiation at 10.1 microns, the reference wavelength which is not absorbed by ethylene gas. The scattered radiation from this source is picked up by detector B. The logarithm of the radiation measured at the two wavelengths represents the gas present in the beam.

When there is no gas present in the beam, detectors A and B have essentially the same outputs. With a small amount of gas present in the beam, the measurement signals detector A decreases as shown in figure 1. For a larger concentration of gas, the output of detector A decreases further.

Consider the case when no gas is present in the beam, various extraneous sources can affect the beams. For example, if the spot illuminated on the ground is a black body at a very low temperature, its reflectivity is low so that low levels of radiation are reflected back; however, the measurement and reference beams are affected identically and the ratio is unchanged. Similarly dust in the beams will absorb and scatter the radiations, but again the ratio is unchanged.

SECTION 3: THE ADVANTAGES OF USING LASER ENERGY

The word laser is an acronym for Light Amplification through the Stimulated Emission of Radiation.

The laser has four unique properties which distinguish it from a conventional light source and make it highly suitable for gas detection over long distances.

Directionality: The light emitted from a laser is well collimated and spreads very little as it travels through space. In contrast, the light from a conventional light source such as a light bulb is emitted over a wide angle. For example, if the beam diameter at the laser output window is approximately 1.5mm, 500 meters away, it will have spread to less than 1.0 meter diameter. This property makes lasers ideal for long distance measurement.

Intensity: Lasers concentrate large amounts of light energy into a very small beam. To illustrate, the intensity (power/area) of a 5mW laser is approximately 25 watts/cm^2. This high intensity leads to significant improvements in signal to noise ratio.

Monochromaticity: Monochromaticity means that laser light is one color, i.e., wavelength. In the case of a Helium-Neon laser, this wavelength is 3.3922 microns. By contrast, the light from a light bulb contains many different frequencies or wavelengths. Monochromaticity makes the laser excellent for spectroscopy, which requires a narrow frequency source.

Spatial Coherence: Light waves emitted from a conventional light source travel randomly in many directions at various amplitudes and frequencies. Laser light waves, however, travel in a very controlled, uniform manner, all having the same phase, amplitude and direction at any point in space.

The above characteristics enable large amounts of energy to be directed along a beam onto the plant. All this energy is at the required infrared wavelength. This combination permits clouds of certain gases of 1.0 ppm and below to be detected at ranges of 500 meters and upwards.

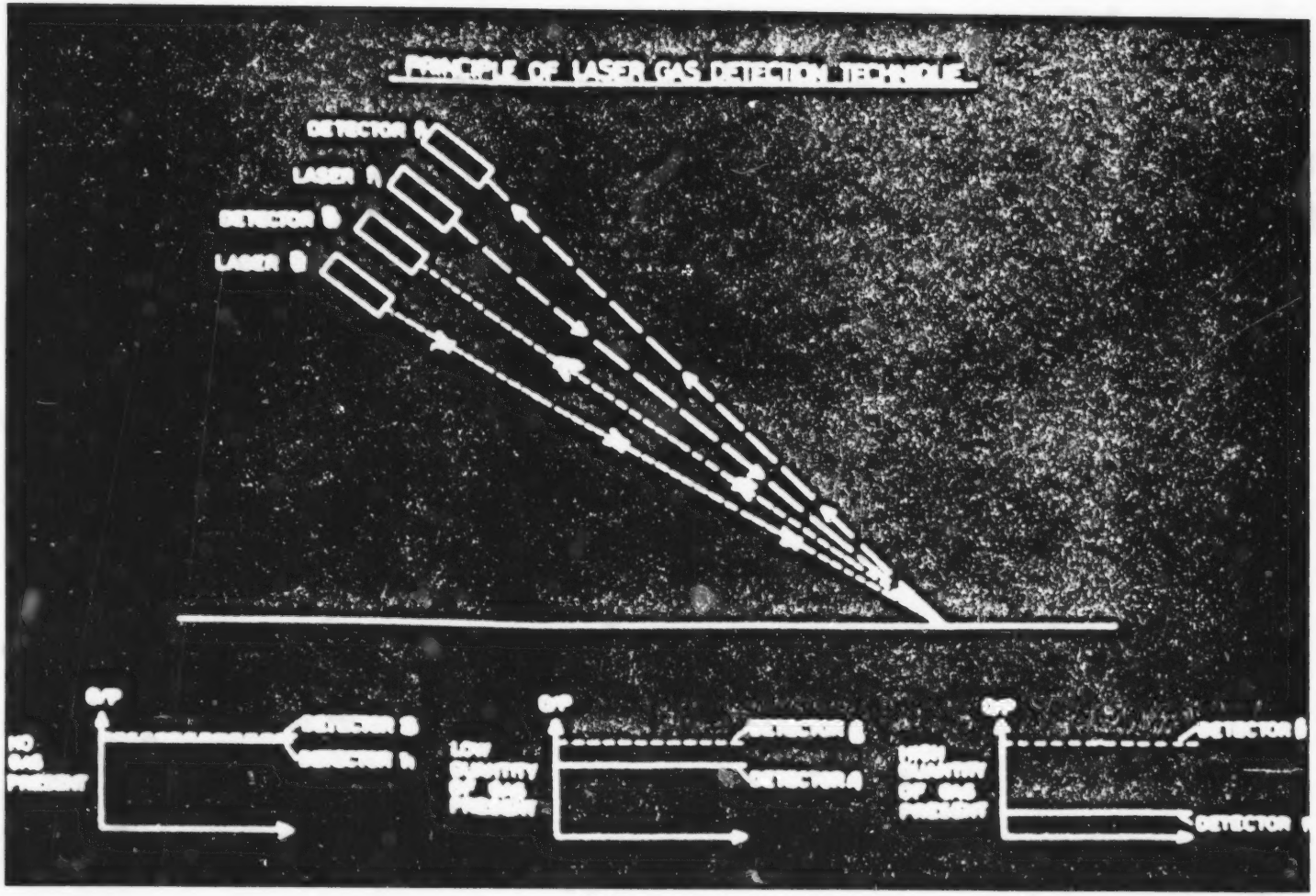


Figure 1: Principle of Laser Gas Detection Technique

The instrument therefore has a major advantage in that the effects of extraneous sources are cancelled and do not significantly effect the measurement.

The instrument output signal is not affected reflecting from bricks, metal or vegetation; neither is it affected by atmospherical temperature, pressure, humidity, dust or other gases in the beam.

A major feature of the instrument is that it is automatically fault supervised and self-calibrated. During the scanning cycle, the beam can be directed onto a transparent canister containing a known concentration of ethylene gas. Any small deviation from the correct reading can be automatically corrected thereby eliminating measurement errors. A major deviation is immediately annunciated as a fault.

For detection of ethylene gas, two 5 watt continuous carbon dioxide lasers are used. One detector (not two as described for ease of explanation) is employed to detect simultaneously the measurement and reference wavelengths. The two laser beams are coaxial so that they illuminate the same areas; the size of the illuminated area is a spot approximately one metre in diameter.

The typical response time for the system is 10 milliseconds. This permits the beams to be scanned at speeds of 360 Km/Hr (hence its application for aircraft surveillance). A typical plant application is shown in figure 2 where the equipment is mounted on a tower outside the hazardous plant area and monitors the main elevation of the process plant.

The range of measurement of the instrument is from one to 30,000 ppm metre and higher depending on the gas being detected. 10 ppm.m. represents a 10 metre cloud of 1.0 ppm. gas or 1.0 metre cloud of 10 ppm.gas. The typical accuracy is 1% of reading.

Each laser emits 5 watts for two lasers, a total of 10 watts. On the ground the power density is 10 watts per m^2. This is well below maximum permitted exposure levels. The human body radiates about 50 w per m^2. Infrared lasers do not affect the retina and are therefore eye-safe.

The technique can be applied to all gases which absorb infrared radiation; gases which come within this category are alcohol, carbon monoxide, unsaturated and saturated hydrocarbons, vinyl chloride, sulphur dioxide, hydrogen sulphide, nitric oxide, methane, phosgene, aliphatic and aromatic hydrocarbons.

The information can be displayed on a Cathode Ray Tube (CRT) in any convenient form. A central computer controls the scanning and plots the track of the beam on a CRT similar to a radar screen. The outline of a gas cloud can be shown with color changes representing the gas level. Multi-instruments can be employed to provide 3D representations of a cloud.

The system is fault supervised and self-calibrating. The fast speed of response ensures it can provide alarms and shut-down plant quickly even in fast build up situations, and it actively searches for gas leaks or vapours from spills to give an earlier warning of danger.

SECTION 4: GENERAL DESCRIPTION OF EAGLE SYSTEM

A typical EAGLE system is shown overleaf. A CRT is mounted remotely, and the display duplicated in several plant areas as required. (The display may need to be in a control room).

The system uses two lasers which are internally modulated ON/OFF by crystal derived control signals. The "measurement" wavelength, laser A, is modulated at typically 10K Hz and the "reference" wavelength, laser B, is modulated at typically 8K Hz. The two beams are combined and directed to the scanning mirror mounted below the scanning telescope. The mirror is arranged to have a "half-speed" drive in the vertical plane, to ensure that the telescope and laser beam track together.

The telescope and mirror assembly are arranged to scan horizontally by one motor drive, and vertically by a second motor drive, so that an angular scan of 120 degrees may be achieved in the horizontal plane and 80 degrees in the vertical plane.

The scattered return energy is collected in an infrared telescope. At the rear of the telescope is mounted a cadmium mercury telluride detector. The cooling of this detector may be accomplished using an electrically powered Stirling cycle cooling engine, a Joule-Thompson gas cryostat running on high pressure nitrogen gas, or a pellister cooler depending on the infrared wavelengths being employed.

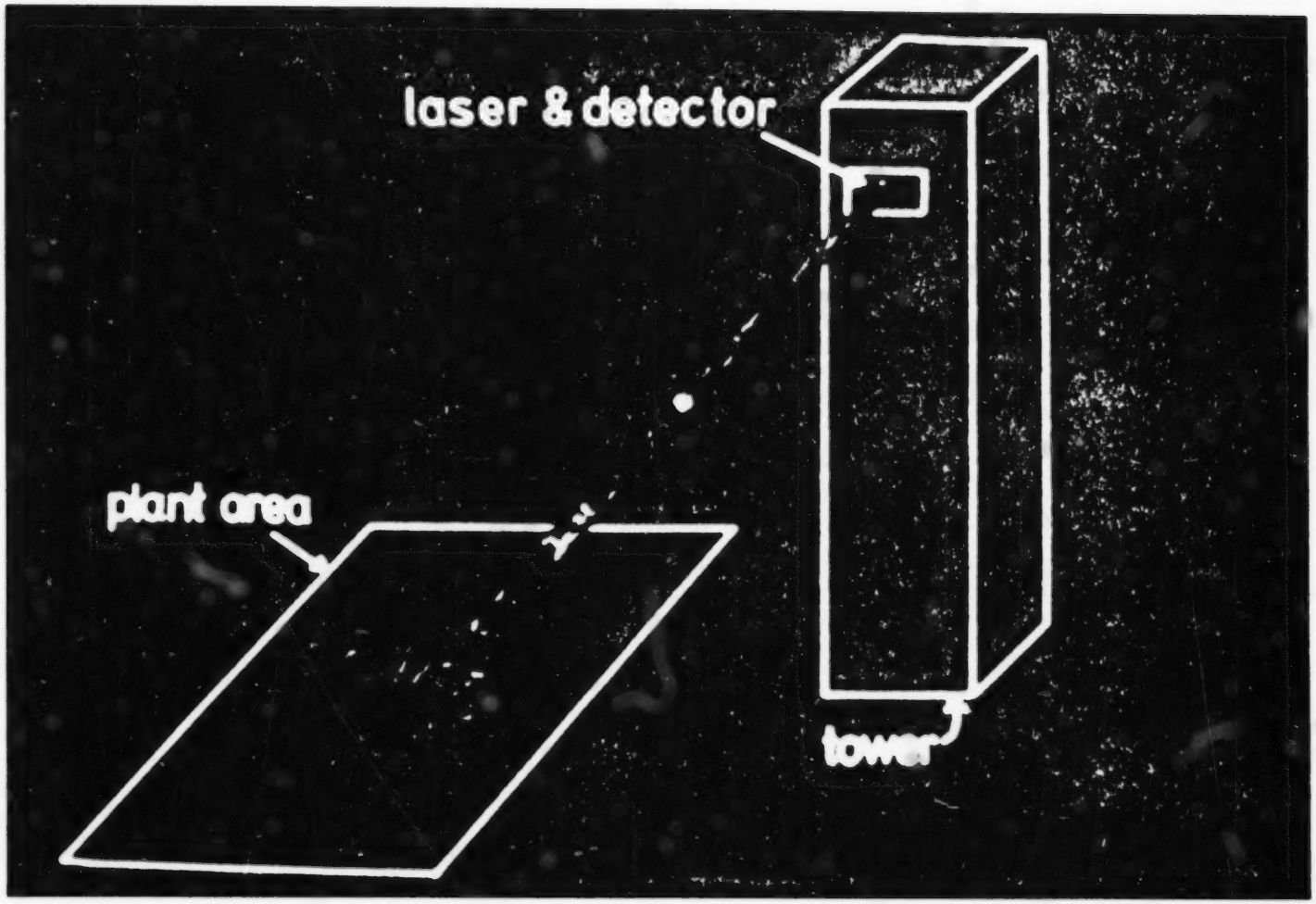


Figure 2: Fixed Mode, Scanning System Illuminating Plant Area for Concentrations of Gas

The electronic signal from the detector is amplified and synchronously detected in two lock-in amplifiers, thus enabling the absorbed and reference signals to be separated.

The scanning system operates under constant acceleration up to constant speed by using a microprocessor system to drive stepper motors.

The ratio calculation required and the information of angular position in two planes is derived in the microprocessor to provide signals for the CRT.

EAGLE System showing enclosure for lasers and coolers, receiving telescope and laser ejection window.

Rear of collecting telescope, showing sterling engine detector cooler and signal cable.

CRT DISPLAY

The monitor will have a 256 x 256 pixels screen. The plant details can be displayed in two ways:

1. A photograph taken from the location of the EAGLE scanner may be produced on a transparency to correct size to overlay the screen.
2. A skeleton outline of the plant may be stored in the memory of the graphics unit and superimposed on the CRT.

The current position of the scanning beam may be indicated by the progress of a marker on the screen.

When the detected gas concentrations exceed certain preset levels, a colored line will be traced on the screen. Six colors will be possible, corresponding to six detection levels. The pattern of gas concentration determined during the scan is stored and maintained on the CRT display until the information is updated on the next scan. When pre-set levels are exceeded, the scan patterns may be automatically modified to give faster and more detailed information on the hazard. Alternatively, manual control may be employed at the operator's discretion.

The display can be used in two modes Normal Mode, as outlined above, or alternatively, Subtraction Mode. Some parts of a plant may have a continuous background level of gas present. These signals if displayed would provide a distracting display, similar to radar system "clutter", and obscure the appearance of a low level signal in a previously "clean" area of the plant. The display may be arranged to subtract these constant background levels at a certain location, resulting in a normally "clean" display until gas levels start to increase.

Any "out-of-limit" conditions of the above can be signaled to the operator to ensure prompt corrective action.

UNITS OF MEASUREMENT

The EAGLE system measures the total amount of gas present in the beam. The unit of measure is 1.0 ppm meter. A 1.0 meter long ethylene cloud in the beam containing 1.0 ppm will give a reading of 1.0 ppm meter. A 10 meter long gas cloud of 0.1 ppm and a 0.1 meter long gas cloud of 10 ppm will give the same reading.

The typical accuracy of measurement is 1.0% of reading.

SYSTEM MAINTENANCE

At six monthly intervals, a planned maintenance procedure should be carried out to check the working performance of the items and to clean/lubricate where required. Items which do not perform to the level required can be easily replaced in the system.

During the maintenance period which should not exceed 6 hours, the plant will be unprotected. This period should therefore coincide with the plant maintenance shutdown (if any). If this is not possible then manual gas watch must be instigated during the period that the system is out of operation. On most plants it is the accepted routine that operators make a tour of the plant every one or two hours with a portable gas detector.

This same safety precaution will be necessary if the EAGLE system fails as indicated by the fault system. The system has been designed to be fully fault supervised and self-diagnostic so that time taken to rectify a fault is kept to a minimum.

MULTI-UNIT SYSTEMS

Multi-unit systems can be employed viewing a plant from different aspects to provide a 3D representation of a gas cloud. To provide protection for extra large complexes and along pipelines it may be necessary to provide overlapping beams. No interference or cross coupling between overlapping beams will occur.

This is guaranteed by employing different modulating frequencies for the lasers. This ensures that the detected signal is unique to the appropriate laser with no interference.

CURRENT DEVELOPMENTS

GP-Elliott has a policy of constant product development. Equipment supplied may vary in some respects from the above description.

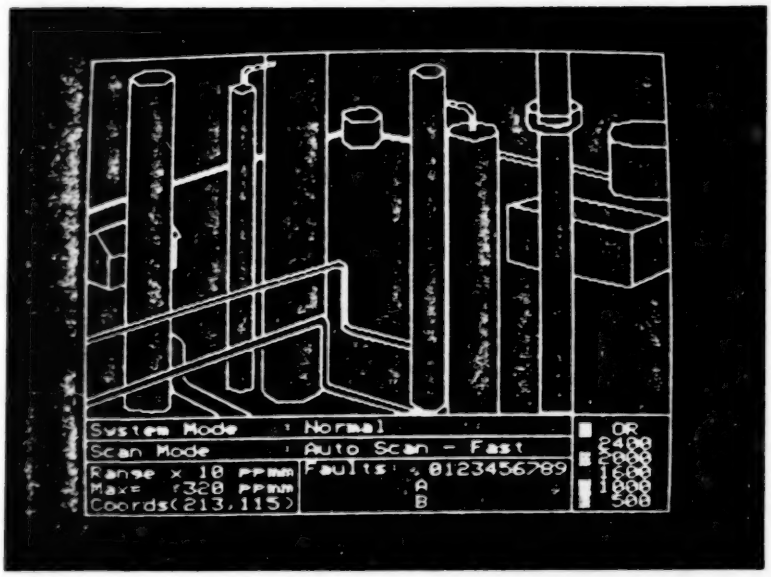


Figure 3: Operator CRT Display of Plant: No Gas Present

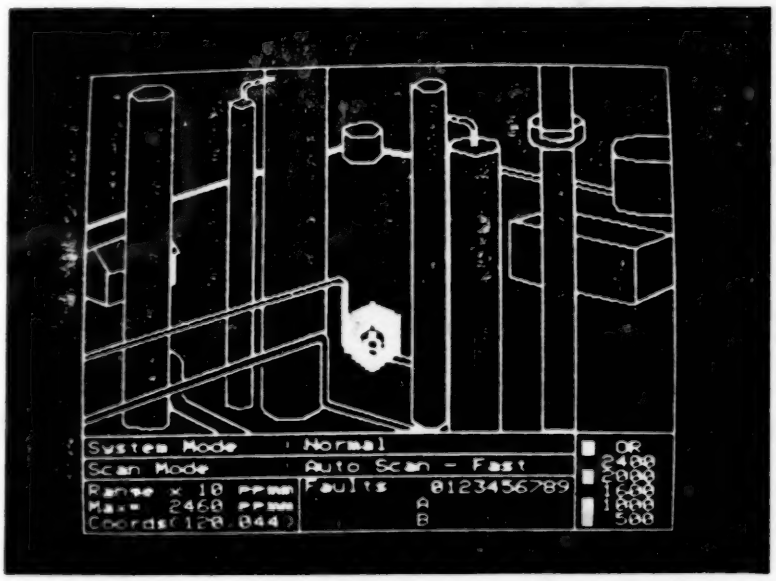


Figure 4: Operator CRT Display: Gas leak highlighted on Pipe Run

SECTION 5: TECHNICAL SPECIFICATION OF EAGLE SYSTEM

Note: This technical specification represents the general design aim for a family of EAGLE systems. The parameters for a particular set of equipment may vary, and are subject to change without notice.

Environment

Temperature Range	$-10^{o}C$ to $40^{o}C$
Humidity	95% relative humidity
Atmosphere	High saliferous with sand and gypsum dust.
Vibration	0.03 g at 5 Hz 0.1 g at 100Hz 2 g shock

Angle of Movement

Elevation	80^{o} total movement
Azimuth	120^{o} total movement
Accuracy of Positioning	2.m radians equivalent to 0.2 m @ range of 100 meters.
Maximum Speed of Movement for Fast Scan	60^{o} per sec.
Beam Size	10 m radians (whole angle) equivalent to area of 1.0 meters diameter illuminated at 100 meters.

Power Requirements		4.0 kW 240/120 V AC 50/60 Hz
Approximate Size of Cabinet		1500 mm long 820 mm wide 800 mm high
Weight of Cabinet		140 kg for CO_2 system 80 kg for He Ne systems
Approximate Size of Telescope		500 mm long 245 mm diameter
Detector		Cadmium Mercury Telluride diameter 2.5 mm
System Response Time		Less then 10 m seconds
System Warm Up Time		30 minutes
Lasers	CO_2	He - Ne
Power	2 W	10-50 MW
Beam Diameter	2.0 mm	1.5 mm
Beam Divergence	10 m rad.	1.8 m radd.
Transverse Mode	TEMoo	TEMoo
Plasma Excitation	RF	Direct Current
	Transverse Excitation	Self-Starting
Wavelength Stability	500 M hz	1500 M Hz
Laser Cooling	Closed Cycle Water Cooling $15^{o}C \pm 1^{o}C$	Not Required (Ambient air Cooling).

Detector Temperature	$77^{o}K \pm 1^{o}K$	$200^{o}K \pm 1^{o}K$
Detector Cooling System	Stirling Cycle Engine	Peltier Cooler
CRT Monitor	EV 605a or similar	
	256 x 256 Pixels Resolution	
Fault Indications	a) Low Laser Power (2 off) b) Low Back Scattered Energy (2 off) c) Scanning Failed d) Microprocessor Fault e) Detector Temperature f) Functional/Calibration Fault	
Range CO_2 System	0 to 500 meters extending to 1000 meters	
Alarms	Low/High preset with switched outputs (volt free contacts) to operate remote sirens and/or emergency shutdown.	
Range of Measurement	Typically 1.0 to 30,000 ppm meter can be extended to higher values depending on gas.	
Accuracy of Measurement	1.0% of reading of certain gases	
Normal Scan	6,000 m^2 in one minute	
Fast Scan	22,000 m^2 in one minute with minimum detectable level of 100 ppm meter.	
Manual Scan	A manual position controller is provided. This unit is employed to set up and program the automatic scan system.	

Meter Output	A meter calibrated in three ranges
	0 - 10 ppm meter
	0 - 100 ppm meter
	0 - 1000 ppm meter
Modulation of Lasers	CO_2 lasers. Direct Modulation
	Measurement laser at 10.0 K Hz approx.
	Reference laser at 8 K Hz approx.
Microprocessor Card	Intel SBC 80/30 Card containing
	8085 8 Bit microprocessor
	4 K Eprom
	16 K bytes RAM
	Interrupt controller
	One series part
	3 parallel ports
	Timer
Computer Storage Card	Intel SBC 064 Card
	64 K RAM storage

Figure 3 is the general view of a plant as displayed on a monitor swept by the EAGLE equipment. Figure 4 shows this view with a gas cloud rising from the plant. The text at the bottom of each display describes the system mode, and the scan mode. In normal scans, 3 ms. integration time is allowed for each point, and in slow scan mode, 30 ms. for each point. The range factor is automatically displayed depending on range selected, and permits the 6-color patterns to be used for display of detection levels.

SUBSIDIARY DISPLAYS

A subsidiary meter (digital or analogue) may be used to indicate the gas detected at the beam's current positions, or alternatively, to show the highest levels encountered in each scan.

Alarm lights or audible warnings are provided to warn plant operatives or control room personnel when certain pre-set levels are exceeded.

INTEGRATION TO PLANT SUPERVISORY EQUIPMENT

Signals may be generated as required to provide inputs to Fire and Gas detection systems already in use, or to provide signals for Shutdown systems or other Process Control Systems.

FAULT MONITORING

The EAGLE system includes monitoring of vital systems conditions, namely:

1. Laser output power for both wavelengths.
2. Correct operations of overall cooling system.
3. Correct operation of cooler.
4. Detector signal level.
5. Correct operation of scanning system.
6. Correct operation of local power supplies
7. System "Watchdog" timer to ensure correct functioning of micro-processor systems.

SECTION 6: EXAMPLES OF GAS SPECIES DETECTED BY LASER

Table 1 lists gases that are capable of being detected by CO2 lasers. Two most important gases, ethylene and phosgene, can be extracted and suitable equipment described.

SECTION 6.1: ETHYLENE

Ethylene is a strong absorber of infrared energy in the wavelength region 9.5 to 11.5 microns. A carbon dioxide laser has a natural frequency of 10.6 microns and can be readily tuned to operate at wavelengths over the range of 9.2 to 11 microns. There are over 80 different laser lines, i.e. wavelengths available in this range. Because of its high power the CO2 laser is highly suitable to detect ethylene.

The system employed on a polyethylene plant in the UK to detect ethylene used two CO2 lasers operating in the 10 micron band. The measurement laser is tuned to line P14 (10.532 microns) which coincides with an ethylene peak. The reference laser is tuned to a nearby line which is not absorbed by ethylene.

This wavelength combination enables measurements to below 1.0 ppm meter to be successfully made and for a range exceeding 1.0 Km to be achieved. Other wavelength combinations in the 9.0 micron band have provided a similar performance.

The use of infrared energy in the 10 micron region requires a detector which is cooled at 77^{o} Kelvin (-200^{o}C). This is achieved with a

Stirling Cycle Engine, which provides continuous operation and eliminates the need for liquid nitrogen bottles.

Table 1 lists a selection of other gases which have strong absorption in the CO2 laser range. By selecting combinations from the 80 laser lines available, these gases can be detected at low and high quantities.

SELECTION OF GASES CAPABLE OF BEING DETECTED BY A CARBON DIOXIDE LASER SYSTEM

TABLE 1

Ammonia	Perchloroethylene
Acetonitrile	Trichloroethylene
Benzene	Tetrachlorethylene
Butadiene	Vinyl Chloride
Butene	Water
t-Butanol	
Chloroprene	
Chloroethylene	
Cyclohexane	
1, 2-dichloroethane	
Ethylene	
Ethylene oxide	
Ethyl mercaptan	
Furan	
Halocarbons	11, 12, 113
Iodopropane	
Iso-propanol	
Methyl Chloroform	
Methyl Ethyl Ketone	
Methyl Mercaptan	
Methanol	
Monochloroethane	
Ozone	
Phosgene	
Propane	
i-Propanol	
Propylene	

SECTION 6.2: PHOSGENE

Tests carried out by high resolution spectrometers shows phosgene has good absorption characteristics at specific lines in the IR spectrum and the equipment for on-line detection would be a similiar configuration to that described for ethylene above. A perimeter sweep of the particular plant is required, with careful positioning of the EAGLE scanner to detect as early as possible leaks or spills from critical areas of the plant.

A fixed system would comprise an EAGLE scanner similar to the unit shown in Section 4.0 above and overleaf, with an isotope of CO2 as the lasing gas. The system is located on a tower 50 - 150 feet high, depending on the plant to be scanned.

The outputs consist of concentration of gas in ppm meters, superimposed on a geographical mimic of the plant on the system CRT in the control room.

SECTION 6.3: METHANE AND GENERAL HYDROCARBONS

Methane is a strong absorber of infrared energy in the region of 3.3 microns.

A helium - neon laser can be made to lase at 3.39 microns which coincides with an absorption peak for methane. A second laser can be constructed to lase at a slightly different wavelength. At this wavelength, there is little absorption from methane. These two lasers provide the measurement and reference wavelengths and permit measurements down to typically 3.0 ppm meter to be achieved.

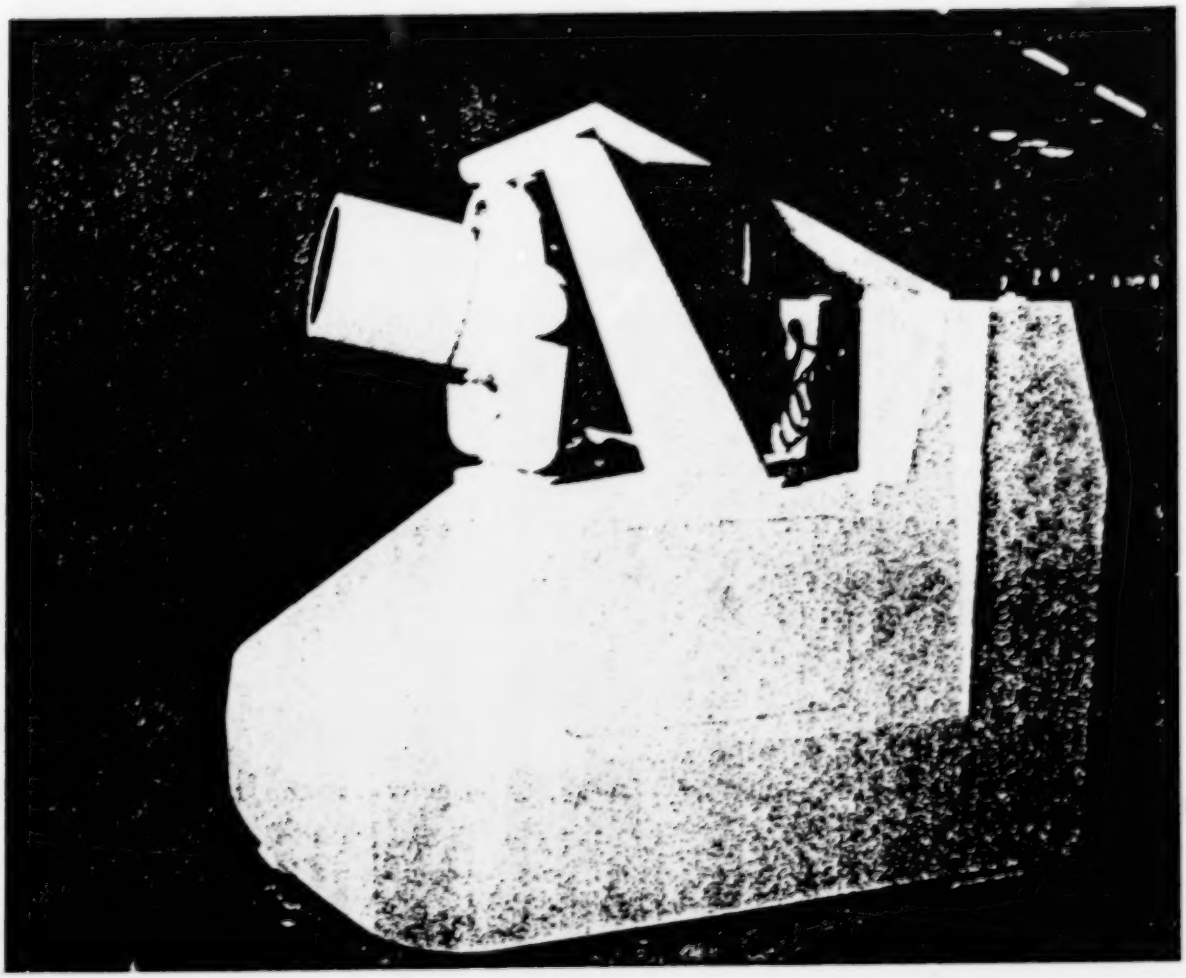


Figure 5: System for application in the 10 - 12 micron region, using CO2 Lasers.

Checks with other hydrocarbons have shown that they do not cause significant differential absorptions at the two wavelengths; the system is therefore specific to methane.

In this wavelength region, the infrared detector requires cooling to 200^{o} Kelvin; this is achieved with a Peltier cooler.

Hydrocarbons in general are strong absorbers of infrared energy in the 3.3 micron bank due to the C-H stretching vibration. Use of lasers in this region permit a general hydrocarbon detector to be constructed. With the measurement wavelength at 3.3922 microns and the reference suitably chosen, a detector for pentane, propane and butane is obtainable as the differential absorption is then substantial for all three gases.

The lasers at the 2 - 5 micron range are lower power than in the 10 - 12 micron region, and so at the former wavelengths, portable systems are appropriate for monitoring of local areas.

The portability can be accomplished by truck or aircraft/helicopter which has particular application for pipelines.

Fixed Installations

For fixed installations, a system can be configured using a sampling chamber for extracting samples of the atmosphere and shining the laser energy across the sample tube or duct. With the differential absorption technique applied, it gives the mass of gas in the tube or chamber. The advantages of this technique is that of speed of detection and accuracy. As with all forms of detection by laser, the range of the

system can be extended by use of reflecting surfaces to steer the laser energy in a predetermined direction, with a parallel beam.

SECTION 6.4: DETECTION OF OTHER GASES

Table 1 in Section 6 lists gases which have absorption peaks in the 10 micron region and can therefore be readily detected with carbon dioxide lasers.

Table 2 lists gases which can be detected by other available lasers. It will be noted that some gases can be detected by several different laser types. For example, propane occurs in the list of CO2 lasers, DF lasers and also helium neon lasers. This arises because propane has strong absorption peaks at 11 microns, 7 microns and 3.3 microns. The lasers used for a given installation depend on range of gas concentration required, distance over which measurement is to be made and possible interfering gases.

The detection of CO and CO2 is of major interest because these are products of industrial processes including power generation. With a response time of about 10 ms., the control of boilers or steel furnaces can for example be 'fine tuned' or use of raw materials optimized for savings in running costs, and improvements in plant performance.

SELECTION OF GASES CAPABLE OF BEING DETECTED BY CURRENTLY AVAILABLE LASERS. SEE TABLE 1 FOR GASES DETECTED BY CARBON DIOXIDE LASERS

CARBON MONOXIDE LASER

Ammonia
Acetaldehyde
Benzene
Butadiene
Butene
Ethylene
Nitric Oxide
Nitrogen Dioxide
Propylene
Propylene Oxide
Toluene
Vinyl Chloride
Water

DEUTERIUM FLUORIDE LASER

n-Butane
Iso-butane
Carbon dioxide
Hydrogen chloride
Methane
Propane
Nitric Oxide
Nitrogen Dioxide
Nitrous Oxide
Sulphur Dioxide

HYDROGEN FLUORIDE LASER

Hydrogen Fluoride
Nitrogen Dioxide
Nitrous Oside
Carbon Dioxide
Carbon Monoxide

$C^{14}O_2^{16}$ LASER

Phosgene
Ethylene Oxide

$C^{12}O_2^{18}$ LASER

Sulphur Dioxide

TABLE 2

SECTION 7: APPLICATIONS FOR THE EAGLE GAS LASER SYSTEM

A recent market research has revealed a large number of possible applications for the EAGLE Instrument used either in the scanning mode, mounted on a vehicle/aircraft or in the fixed beam dedicated mode. These applications can be categorized as follows.

A) Scanning to Protect:

1) Petrochemical plants/complexes
2) Offshore platforms (especially wellhead platforms)
3) Terminals
4) Refineries
5) Docks and Airports
7) Ships (especially oil tankers and LNG carriers)
8) Coal mines and other mining operations
9) Repair works (on roadways and high risk installations)
10) Other installations

B) Mounted on Transporation:

1) On aircraft to overfly pipelines, storage tanks, etc.
2) On aircraft and road transport to check for atmospheric pollution
3) On road vehicles searching for gas leaks on roads, pavements, walkways, etc.

C) Non Scanning Installations

1) To protect air intakes to turbines/air conditioning ducts.
2) To detect leakage from flare stacks
3) To protect equipment from special hazards, over turbines, well heads, etc.

4) To establish air flow in special installations such as air condition systems (using tracer gas).

5) To detect composition of atmosphere.

6) To detect composition of exhausts from aero engineers and internal combustion engines.

7) To protect storage tanks, spheres, bund areas by directing the beam around the object.

8) Perimeter fence protection.

FLEXIBILITY OF SYSTEM

Because of the flexibility of the EAGLE System, the equipment can be instructed to scan part of a plant during the early days of construction and then the scanning area can be readily expanded to take in more plant as this comes on stream. This is particularly important where construction teams must be protected from nearby operating plants.

The changing of the scanning area takes a few minutes only: at the same time, a new transparency of the scanned area showing the plant outline is laid on the CRT.

APPENDIX 2.0.7

Health & Safety Executive

Red Hill
Sheffield S3 7HQ
Telephone 0742 78141
ext
Telex 668113

Mr J A Amirault
Jacques Whitford and Associates
1046 Barrington Street
Halifax N5
B3H 2R1
Canada

Your reference

Our reference

Date 29/11/82

Dear Mr Amirault

METHANE DETECTION IN COAL MINES

Dr Firth has asked me to respond to your enquiry. As you are aware there are very many instruments and techniques available for methane detection. I have enclosed a print out of all those known to be available in the UK. To assist you I have also enclosed a summary based on the techniques used.

At present the bulk of methane detection in UK mines is carried out by catalytic (0-5%) and thermal conductivity (0-100%) devices. IR is used to monitor general body levels via the tube-bundle system. Remote head IR devices are becoming available which may find use in mining.

Laser scanning techniques developed for atmospheric monitoring, are not at present considered suitable for use underground. The present generation of acoustic devices are being phased out in the UK. However, development work at the National Maritime Institute may lead to sufficient improvement for reappraisal of the technique.

I hope you find this information of value. If you require any further details please contact me again.

Yours sincerely

S J Gentry
Catalytic Sensor Section

METHANE DETECTION IN COAL MINES

Summary of techniques in use or under development in the UK.

TECHNIQUE	INST. PRINTOUT	COMMENTS	RESEARCH& DEVELOPMENT
catalytic	yes	0-5%v/v: large no. of instruments available most widely used technique for this range: hand-held and fixed installations used by NCB.	NCB: development carried out at MRDE(Bretby) and regional Scientific Control Labs. HSE: development of rapid response and poison resistant systems.
semiconductor	yes	generally 0-1000ppm: not suitable for high concentrations:used as "sniffers" in surface industry: not used by NCB.	HSE and others: effort directed towards ppm levels of toxic gases.
thermal conductivity	yes	0-100%v/v: most widely used technique for high concentration: used by NCB in methane drainage and roadways.	No known research in the UK.
acoustic	no	some use in methane drainage in the UK: being phased out due to problems with water vapour.	National Maritime Institute are developing an acoustic system for atmospheric monitoring.
interferometry	yes	not commonly used in the UK.	No known research in the UK.
infra-red	yes	0-100%v/v possible but discrimination poor at high concentration: used by NCB in conjunction with tube-bundle.	Some research in British universities eg Edinburgh. Remote head systems are being developed; for example:- Astro Inc. (Texas).
laser scanning	see ir.	0-30,000ppm.metre: the present systems would require considerable de-tuning to operate in %methane.	Research carried out by ICI, Hull Univ., CEGB and G.P.Elliot Ltd. into environmental monitoring.
Raman scattering	no	no instuments available	No known research in the UK.

APPENDIX 2.0.8

Energy, Mines and Resources Canada
Research and Technology
Canada Centre for Remote Sensing
2464 Sheffield Road
Ottawa, Ontario
K1A 0Y7

Énergie, Mines et Ressources Canada
Recherche et technologie
Centre canadien de Télédétection
2464, chemin Sheffield
Ottawa (Ontario)
K1A 0Y7

Your file Votre référence

Our file Notre référence

October 29, 1982.

Mr. John A. Amirault,
Jacques, Whitford and Associates Ltd.,
1046 Barrington Street,
Halifax, Nova Scotia.
B3H 2R1

Dear Mr. Amirault:

RE: Methane Detection in Coal Mines

Thank you for your letter of October 7, 1982 in which you wondered if the Canada Centre for Remote Sensing was developing any techniques which might be suitable for the detection of methane. Although some of our scientists have had experience in related fields, it is not one of the topics being pursued by the Centre where the sensor research programs have concentrated generally on the development of airborne systems which can collect land and water data for a wide variety of users. The Atmospheric Environment Service in Downsview, Ontario has sensor development projects for the atmosphere and its constituent gases.

There are a number of properties of methane which could be of use in the remote detection of methane in coal mines, including its infrared signature, Raman spectrum, multiphoton spectra, Stark spitting, derivative spectra, reaction kinetics and photolysis, mass spectra etc.

Several remote sensors of methane in air have been developed which use the characteristic infrared spectrum to measure the methane concentration. Although the passive instruments have been designed to use either sunlight or the differential emission from the target gas and background, minor modifications (such as the addition of a light source) should make them usable under mine conditions. For more information, you might like to contact the following companies:

1. Barringer Research Limited,
   394 Carlingview Drive,
   Rexdale, Ontario M9W 5G2
   Tel. 416-675-3870 ATTN: Dr. C. Cumming

.../2

Canada

Reference: GASPEC (methane sensor)
HHRR (hand held reflectance radiometer)
COSPEC
Infrared filter spectrometer

2. Moniteq Limited,
630 Rivermede Road,
Concord, Ontario L4K 1B6
Tel. 416-669-5334 ATTN: Dr. H. Zwick

Reference: GASPILS (methane sensor in development)
Probar

3. Optech Limited,
701 Petrolia Road,
Downsview, Ontario M3J 2N6
Tel. 416-661-5904 ATTN: Mr. S. Sizgoric

Reference: Active Laser Sensors

4. Opto-Electronics Ltd.,
Unit 9, 2538 Speers Road,
Oakville, Ontario L6L 5K9
Tel. 416-827-6214

or Dr. John Reid,
Department of Engineering Physics,
McMaster University,
Hamilton, Ontario L8S 4M1
Tel. 416-525-9140

Reference: Tunable Laser Diode Sensor, and Derivative Spectroscopy

Other companies which may have relevant expertise and ideas are:

5. Ultra Laser Tech Inc.,
Unit 2 - 6415 Viscount Road,
Mississauga, Ontario L4V 1K8
Tel. 416-677-8091 ATTN: Dr. J. Ryan

Reference: Spectrophone (an opto acoustic trace gas analyser)

6. Scintrex,
222 Snidercraft Road,
Concord, Ontario L4K 1B5
Tel. 416-669-2280 ATTN: John Robbins

7. Photo-Chemical Research Associates Inc.,
45 Meg Drive,
London, Ontario N6E 2V2
Tel. 519-686-2950

In addition, several ambient sensors are available that sample the air using a vacuum or flowing system. These include for example, sensors made by Mine Safety Appliances (Toronto), the Sciex TAGA (a mass spectrometer system probably of greater advantage for larger hydrocarbons), the Miran range (incorporating a multipass absorption cell) produced by Foxborough Wilks, various Beckman instruments based on the photolysis discharge technique, and a number of others that use the characteristic absorption or emission spectra of methane. More information on these sensors should be obtainable from:

8. Sciex,
   Unit 202,
   55 Glen Cameron Road,
   Thornhill, Ontario L3T 1P2
   Tel. 416-881-4646

9. Beckman Instruments Inc.,
   Process Instruments Division,
   6465 Northam Drive,
   Malton, Ontario L4V 1J2
   Tel. 416-677-1164

10. Foxborough Canada Inc.,
    3289A Lenworth Drive,
    Mississauga, Ontario L4X 2H1
    Tel. 416-625-4111

If none of the above systems prove suitable, you might like to consider a technique based on non-linear or resonance spectroscopy. A number of recent papers have been published on the spectroscopy of methane by, for example, G.W. Hills, R.W. McKellar, J.W.C. John's, J. Reid, or T. Oka etc., and current research is, I believe, being carried out at the National Research Council (Herzberg Institute of Astrophysics, Ottawa, 613-992-6917, Dr. J.W.C. Johns), McMaster University, the University of Toronto (Department of Physics, Dr. H.M. Van Driel 416-978-4200), National Bureau of Standards, Jet Propulsion Lab etc. This research is not being developed specifically for remote sensing but might be applicable.

I hope the above suggestions provide you with a starting point in your search. If you have further questions you may wish to contact, Dr. Susan Till, of the Sensor Development Section, CCRS, (Tel. 613-998-9060).

Sincerely,

E.A. Godby,
Director General,
Canada Centre for Remote Sensing.

c.c. D. Bruce Stewart, EMR
S. Till, CCRS

EAG/R.O'N/bt

United States Department of the Interior

BUREAU OF MINES

PITTSBURGH RESEARCH CENTER
COCHRANS MILL ROAD
POST OFFICE BOX 18070
PITTSBURGH, PENNSYLVANIA 15236

November 8, 1982

John A. Amirault
Vice-President--Mining
Jacques, Whitford and Associates Limited
1046 Barrington Street
Halifax, Nova Scotia B3H 2R1

Dear Mr. Amirault:

In response to your letter of October 7, 1982, the Bureau of Mines is actively involved in research related to the remote detection of methane. Currently, both the Raman scattering technique and the differential absorption technique are being studied thru contract and in-house research projects. It is felt that both techniques could eventually lead to a mine permissible remote methanometer capable of measuring methane concentrations at remote distances up to 40 feet and at concentration levels of 0.25% and higher.

At the present time, we are in the laboratory evaluation phase of these studies; it appears that initial prototype systems based upon both techniques will be fabricated within the next two to three years.

If more information is required regarding this subject, please contact Mr. Charles D. Litton (412/675-6752) at the Pittsburgh Research Center.

Sincerely yours,

John N. Murphy
Research Director

DEPARTMENT of the INTERIOR
news release

For Immediate Release

Barbara Smith 202/634-1007

RESEARCH CONTRACT ANNOUNCED BY MINES BUREAU

A major component of an instrument to measure--from a distance--the concentration of hazardous methane gas at the working face of a coal mine will be developed under a contract just awarded by the Interior Department's Bureau of Mines.

The $130,000 research contract with Homer Research Laboratories of Bethlehem Steel Corp. in Bethlehem, Pa., calls for the manufacture of a special laser, capable of producing dual wavelengths within a certain range. The laser will eventually be used in a gas monitor that will allow miners to measure methane levels at the face, or cutting area, of a coal mine while standing 20 to 40 feet away.

Methane gas occurs naturally in most coal mines, but at certain concentrations forms an explosive mixture with air. Federal safety regulations require that methane concentrations be measured at least every 20 minutes at the working face of the mine. Other Federal regulations, however, prevent miners from venturing into such areas without first installing temporary roof supports to protect against falling rock.

The Bureau's new contract is the first step toward the development of a monitor that can be used remotely from a safe area, thus improving the safety of miners while reducing the need for temporary roof supports. Under the contract, Homer Research Labs will fabricate and test two prototype dual wavelength light sources, or lasers, with one wavelength tuned to be absorbed by methane and one not. The difference in the intensity of the wavelengths, after they are directed toward the face and reflected back to the source, will then be used to determine methane concentrations.

Work under the contract should be completed in approximately 19 months. Results will be made public.

x x x

(October 29, 1982)

APPENDIX 2.0.10

TELEPHONE CONVERSATION RECORD

Person Called: Dr. Richard A. Elliott Date: 24 Mar. 1983
Person Calling: John Amirault City: Beaverton, ORE

Dr. Richard A. Elliott
Oregon Graduate Center
19600 N.W. Walker Road
Beaverton, ORE
USA 97006

Items Discussed:

Reports work conducted under a research grant from the Homer Research Laboratory of the Bethlehem Steel Corporation, Bethlehem, PA. Their work has been related to the development of a Laser source for methane detection.

A paper reporting their work will be presented to the Conference of Lasers and Electrooptics in Baltimore, MD in May of 1983 entitled "Laser Diode Source for Methane Detection in Coal Gas" delivered by R.K. DeFries and R.A. Elliott

A second paper to be published in April 1983 in the Journal of Applied Physics entitled "High Output Room Temperature Pulsed Operation for Broad Contact Laser Grown by Molecular Beam Epitaxy" by R.K. DeFries, R.A. Elliott et.al.

Elliott advises that work is progressing on the application of suitable lasers and detectors for use in coal mines using differential absorption techniques. Ranging of the system is performed by using twin detectors, one tuned on and one off the methane line. He also informs that patents have been issued to Homer Laboratories for the device.

Elliott also advises similar or related activity being conducted at the Jet Propulsion Laboratory in Pasadena, CA. - contact Mr. Bill Grant: tele: (213) 354-2750

APPENDIX 2.1

Computerized Data Banks Interrogated for Information on Remote Methane Detection via Nova Scotia Research Foundation Library

(1) File Name: RESORS
Operator: Canada Center for Remote Sensing
Energy, Mines and Resources
Ottawa, Ontario
Canada
Date Accessed: September 1982

(2) File Name: DATA PAC QL
Operator: Queen's University
Kingston, Ontario
Canada
Date Accessed: September 1982

(3) File Name: ORBIT, CHEMICAL ABSTRACTS, DIALOG
Operator: Cambridge Scientific Abstract Company
Santa Monica, California
United States of America
Date Accessed: September 1982

(4) File Name: CAN/OLE
Operator: Canadian Institute for Scientific and Technical Information
National Research Council
Ottawa, Ontario
Canada
Date Accessed: September 1982

(5) File Name: APTIC
Operator: Air Pollution Technical Information Center
Palo Alto, California
United States of America
Date Accessed: September 1982

APPENDIX 2.2

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POOR

QUALITY

ORIGINAL